# FLY OR FLEE?

## Evacuation of Airport Terminal Buildings – Possibilities for Computer Simulation

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# Preface

Sometimes reality offers a new view on theory.

In April this year I started this research at the Airport Research Center in Aachen, Germany. I read articles on evacuation, focussed months on the interesting aspects of human behaviour, learnt to work with the Airport Passenger Library, sought emergency-relevant aspects of the architectural environment and then…

… while I was working on my evacuation model…

… theory became reality. On the 11th of September, 2001, after two aeroplanes crashed into the Twin Towers in New York, the world evacuated. In the World Trade Center people tried to save their lives, American airports nation-wide were closed, and bomb threats led to more evacuations all over the world. These events, however terrible they were, gave my research a new dimension, and more relevance.

I would like to thank my TU Delft mentors Uta Kohse, John Stoop and Alexander Verbraeck for their enthusiastic support and useful advices, Edwin Valentin for the help during the design and construction of the new objects for the Airport Passenger Library, the Airport Research Center, especially Tom Heuer, for providing me an interesting subject for my Master Thesis, Niels Bakker (Amsterdam Airport Schiphol) for the valuable co-operation and the floor plans of the terminal, Peter van de Leur (TNO, Centre for Fire Safety Research) for his critical reading and valuable suggestions, professor Sol for his feedback, and of course my family, friends and roommates.

**Rik Kuiper**
*Delft - Aachen,*
*April until December, 2001*

# *Stipjes*

In elk gebouw waar ik geen nooduitgang zie, probeer ik het me voor te stellen: vuur slaat om zich heen en rook verspreid zich. Welke kant ren ik op? Wie waarschuw ik? Ga ik mijn jas nog halen? Het is beroepsdeformatie. Vluchten, namelijk, is mijn beroep.

Eigenlijk weet ik wel, dat je je een evacuatie niet kunt voorstellen, als je er nog nooit een hebt meegemaakt. Zelfs al lees je – zoals ik – tientallen wetenschappelijke artikelen. Ik evacueer. Nee, ik simuleer dat ik evacueer. Ik bestudeer brandende metrostations, doorstroomcapaciteiten van deuren, slechte bewegwijzering, vluchtende mensen die hun koffer willen meenemen, en effectiviteit van alarmsystemen. Ik ga dit omzetten in een computersimulatie. Het is mijn afstudeeronderwerp.

Ik gooi een luchthaven vol met mensen, nee met stipjes, programmeer hoe ze zich gedragen, druk op een knop om een virtueel vuurtje aan te steken, en kijk vervolgens hoeveel er levend uitkomen. Overlijden er teveel, dan moet het architectonisch ontwerp veranderen en doe ik het experiment opnieuw. Dan komen de stipjes op wonderbaarlijke wijze weer tot leven, lopen op dezelfde plek door de terminal, en opnieuw druk ik op de knop. Met de hoop dat er meer in staat zijn te ontvluchten. Het is onschuldig wetenschappelijk gerommel, met als doel veiligere luchthavens te kunnen ontwerpen. Ik ga er hopelijk binnenkort ingenieur mee worden.

In september dit jaar deed iemand een dergelijk experiment. Hij wachtte tot de Twin Towers vol zaten met stipjes en drukte op de rode knop van het terrorisme. Het schokte mij en de wereld, want het waren geen gewone stipjes, maar levende mensen met een gezin, een geweten en een geschiedenis. De stipjes belden wanhopig naar huis, zwaaiden met witte doeken naar machteloze camera's, en sprongen uit het raam van de 97ste verdieping. In mijn simulatie doen ze dit nooit. Gelukkig niet.

In mijn simulatie kun je direct zien hoeveel mensen er zijn omgekomen. Zo gaat dat in de wereld van nullen en enen. Ze worden niet eerst vermist, liggen niet dagen op de intensive care, worden niet met afgerukte ledematen onder een ingestort gebouw gevonden, hoeven niet geïdentificeerd te worden. En er spreekt geen losgeslagen wereldleider over oorlog, revanche en – heel diplomatiek – het uitroken van de daders.

Ik kijk trouwens ook niet met gespannen blik en een rood hoofd naar de beelden op mijn monitor.

Het doel van de aanslagen in Amerika was ook niet om een veiliger wereld te scheppen, zoals bij mijn simulatie. Het doel was om zoveel mogelijk mensen onder de ineenstortende torens te verbrijzelen. We kunnen dus niet even terugspoelen, de torens herontwerpen, opnieuw met stipjes vullen en kijken of er de volgende keer minder doden vallen. Zo gaat dat niet in de echte wereld.

Ondertussen, terwijl deze echte wereld langzaam zieker wordt, gaat de wereld van mij en mijn stipjes gewoon door. Het lijkt onzinnig, maar het moet. We hebben nog steeds als doel de wereld veiliger te maken, ook als er tegelijkertijd mensen de wereld onveiliger proberen te maken. Het verschil is alleen, dat sinds de elfde september mijn levende stipjes een beetje meer zijn gaan leven, en mijn dode stipjes een beetje meer dood zijn.

**Rik Kuiper**
*(gepubliceerd in Delta 28, september 2001)*

# Summary

They are almost entire cities, our present airport terminal buildings, complex 'machines' which fulfil many functions at the same time. The analysis of the movements of human beings through the building becomes more and more important, since buildings are judged upon their efficiency, user-friendliness, and safety.

Since 1999, Delft University of Technology is working on a generic tool to assess terminal operations, the Airport Passenger Library. This simulation tool, built using the eM-Plant simulation language, should help solving problems concerning check-in planning, staff planning, gate planning, baggage reclaim planning, baggage handling, and passenger movements.

This research, executed at the Airport Research Center in Aachen, Germany, aims at exploring the possibilities of the Airport Passenger Library in evacuation modelling. The objective of this research will be:

> *Describe the process of evacuation in conceptual models and translate these models into new generic building blocks for the Airport Passenger Library, in order to be able to test the emergency safety of passenger terminal designs.*

We aimed at creating an evacuation model that stays close to reality, is generic and therefore re-usable, and contains a comprehensible user interface, animation, and output.

The large concentration of people in a relatively small and closed area can cause problems when unpredicted situations appear. Emergencies in terminals should lead to a quick and safe evacuation of building occupants, in order to avoid casualties. The success of evacuation depends on four major interacting factors: the emergency and its consequences (e.g. smoke and fire production and movement), human behaviour in case of emergency, building characteristics, and management decisions.

Since covering the entire field was impossible, we focussed only on human behaviour and construction. Concerning the building characteristics we can mention, that the behaviour performed in case of emergency depends highly on the physical location and properties of the area, and on the current activity performed within the area. Besides, the terminal layout has an influence on the possible emergencies and the respective evacuations. The presence of underground pedestrian routes and the density of people are important factors. Characteristics of staircases, doorways, signage, public address systems influence escape behaviour significantly.

Within airport terminals, many different occupants can be distinguished, from airline passengers to homeless persons. For evacuation analysis, it is crucially important to examine the nature of behaviour in normal circumstances and therefore during the early stages of an emergency when most time is lost. Problems during evacuation can be caused by heavy luggage, disabilities, and commitment to their current activity, such as having a meal in a restaurant or lining up for check-in. Guidance by emergency services and airline personnel can avoid long walking distances and pre-movement times. Social influences and group behaviour within airport terminals must not be underestimated.

During the implementation phase of this research, we constructed new objects for the Airport Passenger Library, and we changed existing objects. The set of new objects, created to simulate emergency and evacuation, consists mainly of control objects, both on a global as on a local level. The local control objects list the groups currently present within this area, assign them relevant attributes, and order them to choose an escape route.

Theoretically, groups escape according to certain behavioural rules. This behaviour can be seen as a result of the interaction between personal, local and global attributes. In this model, we have two main parameters describing the difference in behaviour, namely pre-movement time (the time between the start of an emergency and the decision to escape) and chosen destination.

Using this evacuation sub-library we can model an emergency within a terminal building. We defined a certain step-order for preparing the simulation and running experiments. The relevant output variables of this simulation model can be subdivided into three levels: global output, local output, and group output.

For validating the model, we used a model of a fictive airport, and a single pier at Amsterdam Airport Schiphol. Since not much validation data is available, in the future we should explore possibilities to gain more quantitative data to validate this model. Accident research is a very important means to enlarge the safety of our built environment.

In general, the model appeared to function properly. Nevertheless, we must conclude that the modelling of processes like this, is still a very complicated matter, incorporating much insecurity.

It is recommended to explore the advantages of a using a tighter grid in which more individual interaction, such as overtaking and crushing around doorways, can be modelled. It is not said, though, that this will lead to better results. To analyse the effect of using smaller areas, we could start to create a more detailed model using the existing library.

If the current representation appeared to be representative, it is recommended to extend the existing object library with new objects such as toilets, stairs, and escalators, and to improve existing objects, such as the shortest path algorithm. Beside this, it would be interesting to introduce a hazard model, describing the development and the effects of the emergency, in order to make the scenarios more realistic.

# PART I

# Problem Definition

# 1 Introduction

They are almost entire cities, our present airport terminal buildings, complex 'machines' which fulfil many functions at the same time. On the airside of the terminal people leave or arrive by plane, while on the landside transportation takes place by car, bus or train. But airline passengers do not just walk in just on time, walk straight through the building from one side to the other, and catch a plane. Airline passengers spend time in terminal buildings, hundreds, thousands of passengers. But what happens if suddenly a fire breaks out?

The reasons for these long stays are obvious. Airline passengers generally arrive earlier at the airport than for example train passengers at the station, because they are subjected to stricter and more complex procedures, like luggage check-in and security control. Beside this, the increase of the number of hub-and spoke connections[1] imposes an increase of transfer passengers. Since flight transfers generally take more time than changing trains, they spend their time in the terminal. Airports give tourists the idea that travelling is entertainment: it offers possibilities for tax-free shopping, having dinner in a restaurant, or even seeing a movie.

The large concentration of people in a relatively small and closed area can cause problems when unpredicted situations appear. For example, from the recent history of airport industry becomes clear, that serious fires and other emergencies are by no means a rare occurrence. After the attacks on the WTC Towers in New York on the 11th of September, 2001 for example, many American airports have been evacuated, either preventively, or because of serious threats. Some other recent terminal evacuations:

- Colombo International Airport – July 24th, 2001
- Amsterdam Airport Schiphol – April 8th, 2001
- Calcutta Airport – February 10th, 2001
- Amsterdam Airport Schiphol – January 18th, 2001

Fires and other emergencies in terminals should lead to a quick and safe evacuation of passengers and staff, in order to avoid casualties. Therefore the airport management designs emergency and evacuation plans. Beside this, legislation prescribes minimum distances from each point in the terminal to an emergency exit, minimum capacities of these emergency exits, compartmentation, use of fire resistant materials, et cetera and in many countries designs for new buildings should be checked by the local fire department, before they can be built. Mostly, these procedures are executed quantitatively and based on rules of thumb.

In this research we will explore if and in what way computer simulation could play an additional role in judging the safety in terminals. We aim at implementing an evacuation sub-library in the Airport Passenger Library, an existing simulation tool to simulate passenger flows in airport terminal buildings.

[1] The concept of hubbing means that flights originating from different airports, which are the spokes of a network, arrive at the hub at approximately the same time. The aircraft are then on the ground simultaneously, thereby facilitating interchange of passengers and baggage between aircraft in a short period of time before they depart in quick succession back out along the spokes. (from: Doganis, R. (1991); Flying off Course, The Economics of International Airlines; p.263)

A model like this could help airport designers and planners to test and evaluate their designs before they are built. In the best case, weaknesses in the design can be found in an early stage, directly adjusted, and re-evaluated.

This research is subdivided into five parts. In the first part of this research we will define the problem we have tried to solve during this research project.

In the second part we will explore the existing literature concerning evacuation and simulation of evacuation, focussing on human behaviour and constructional aspects.

We will translate the conclusions of the literature into conceptual models in the third part of this report.

Then, in the fourth part we will describe the phase of implementation. This will concern the design of new building blocks for the Airport Passenger Library, and the application to two airport models.

In the fourth and final part of this research we will evaluate the process and present the conclusions and recommendations of this research.

# 2 Terminal Design and Simulation

In this chapter we will shortly describe the airport terminal design process, and the role of simulation during this process, in order to put this research in its context.

## *2.1 Terminal Design Process*

Passenger transport through the air is still increasing rapidly. New airports arise, existing airports expand quickly. At the same time passengers demand more comfort and safety, both during the flight and in the airport terminals. Obtaining a satisfactory new terminal design requires a long and intensive study. The main reason for this is the large range of possibilities available for airport expansion. The choice for one concept or another depends on many parameters, like prospects of number of passengers, flight schedules, modal split, market prognosis's, available space, available money, security requirements et cetera. An architectural terminal design is not coming forth from mathematical equations with input variables that lead to the perfect one-and-only layout. The typical design, appropriate for a unique situation, should fit into all unique requirements and contextual boundaries.

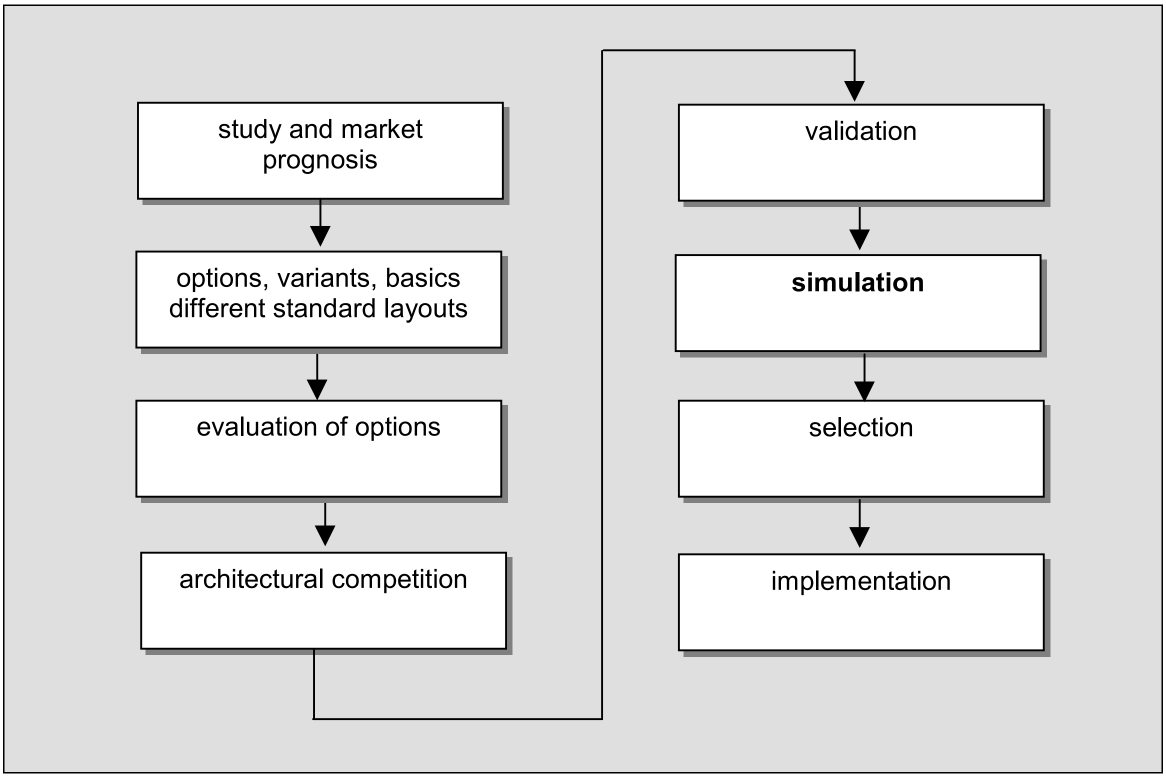


*Figure 2-1: Design process for airport terminals.*

The process of building or expanding airports, as it takes place at the moment, can be seen as presented in Figure 2-1. In the first phase, study and market prognosis, the general requirements for the new terminal are defined taking into account the estimated number of future passengers, expected flight schedules, available space, national and international legislation, et cetera. In the second phase different basic terminal designs are sketched, based on different terminal and pier concepts, which will be described in chapter 9.

In the following phase, these conceptual designs are evaluated, often in a qualitative manner. When the decision is made, an architectural competition is organised, inviting architecture offices to make a new terminal design concerning the set of requirements. The gathered designs will be validated in the validation phase, which can be followed by a simulation study. Finally, the result of the architectural competition, the validation and the simulation is the selection of a certain design that will be implemented.

*Figure 2-2: Design of the Kansai International Airport Passenger Terminal Building by Renzo Piano and Noriaki Okabe.*[2]

## 2.2 Simulation and Terminal Design

Simulation can offer new opportunities to building design. It can be defined as follows:

> *The process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluation of various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system.*[3]

For terminal design, we could think of simulating check-in planning, staff planning, gate planning, baggage reclaim planning, baggage handling, and last but not least passenger movements. By using simulation software we can obtain better insight into the complex processes within the terminal. Bottlenecks in the design will appear in an early stage, so the design can be adapted before it is executed.

One of the problems with the specific step order in the design process as mentioned before (Figure 2-1), is that the phase of simulation is applied in a very late stage of the process, often at the moment that the architectural designs are fully completed. This is an interesting notion, because of the fact that a simulation study could for example show that one of the basic assumptions, formulated in the first two phases, is wrong. This might consequently lead to a step backwards, returning to earlier phases to define new requirements and redesign the terminal.

[2] Picture taken from: www.aij.or.jp
[3] Shannon, R.E. (1975); Systems Simulation: the Art and Science, Prentice-Hall

The main problem concerning simulation at the moment is that the studies are very time consuming and expensive. Available tools need expert skills and lots of specific input data, which means that they are not easily accessible for architects and the airport management. To diminish the execution time and therefore the costs of simulation studies a further development of airport simulation tools is required. As soon as the possibilities of simulation are improved, it can be executed earlier in the design process and it can be used as a supporting tool during different phases, for example starting directly after the different options are explored, as shown in Figure 2-3.

This earlier and more structural simulation support would cause a reduction of time and cost, as it extinguishes certain variants and standard layouts in an early stage of the process. As a consequence, the following stages become less extensive and therefore cheaper. Within a shorter period of time important choices can be made and more energy can be put into the design of better solutions.

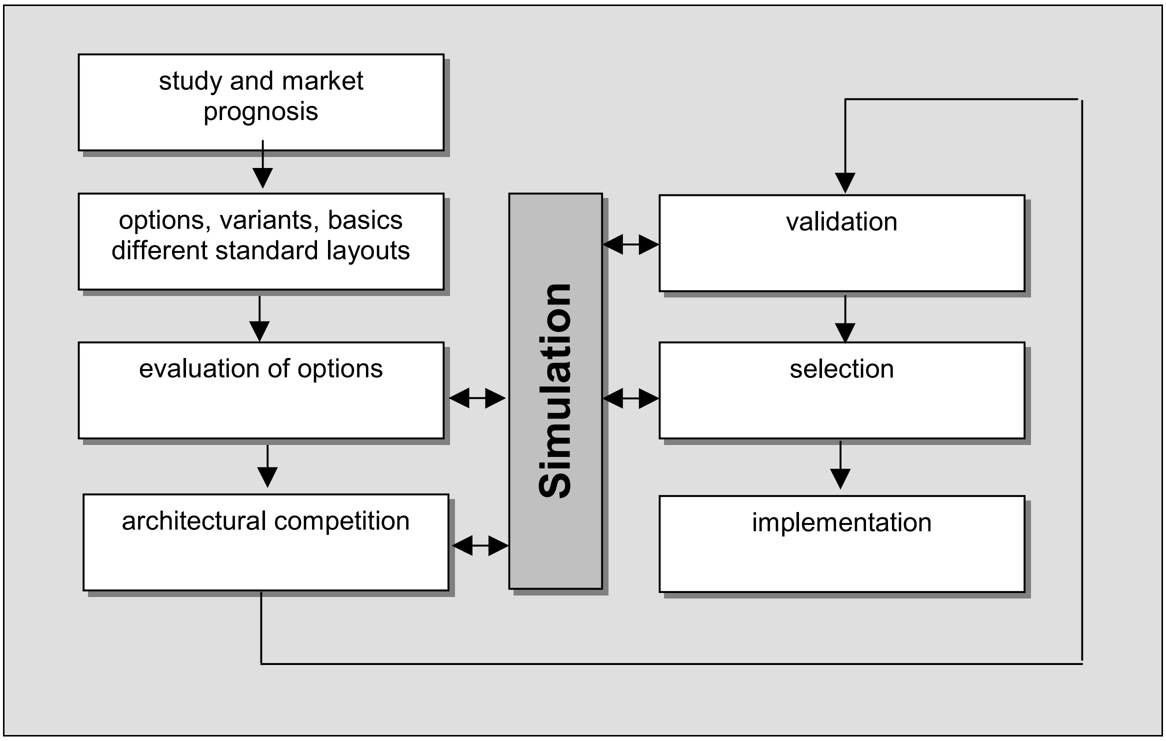


*Figure 2-3: Improved design process for airport terminals with more increased role for simulation studies.*

## 2.3 Airport Passenger Library

In order to obtain quantitative insight into processes such as luggage and passenger flow within airport terminals, in 1998 Amsterdam Airport Schiphol and Delft University of Technology started to develop a simulation tool.[4] This object-oriented tool consists of a certain number of new building blocks or objects, which can be used by the eM Plant simulation language, formerly known as Simple++. Later the Airport Research Center in Aachen, Germany and TBA Nederland in The Hague, the Netherlands joined the co-operation. The library has been under development, and at the same time different

[4] Arends, D. (1999); Using Object-oriented Simulation for a Quantitative Approach of the Terminal Concepts; final thesis Delft University of Technology

projects at Amsterdam Airport Schiphol and JFK International Terminal in New York were accomplished.

The existing Airport Passenger Library is able to describe terminal buildings using the generic building blocks. The library represents the following four aspects of the airport terminal:

- Infrastructure facilities: check-in, passport check, customs, reclaim, gates, shopping, lounges, et cetera.
- Passenger movements: walking around the airport terminal from entrance to the gate or vice versa.
- Passenger activities: shopping, check-in, say-goodbye, waiting, et cetera.
- Information: shortest path algorithm and planning of check-in, passport check, gates, reclaim belts, et cetera.

The infrastructure of the terminal building is composed of different area objects, which are connected. Each area can be seen as a resource that delays the group for a certain period.

The creation of groups of passengers is based upon a flight schedule with departing and arriving flights. Groups can consist of one person or more than one person, travelling together, such as families, or business travellers. A user-defined chance table defines the distribution according to which groups get assigned certain group characteristics, such as the number of persons in this group and the group's walking speed.

Each group consists of at least one passenger, so this model can be seen as a microscopic model, including individual behaviour. The movement of the groups through the terminal is determined by the group's script. This script is a list of consecutive activities, which are to be performed. When groups arrive at an area, they check whether enough capacity is available. If so, they enter the area and the delay that represents either a walking distance or a handling time at a desk, is calculated. The length of the delay depends on the characteristics of both the area and the group.

The centrally located control objects are responsible for the scheduling of flights, the assignment of check-in desks and gates to flights, the creation of passengers, and the calculation of the shortest path between any two points.

An important habit of the Airport Passenger Library is its genericity. On the one hand the library can be used for describing different processes within the same terminal or airport, but on the other hand it can be applied to different airports, without changing the properties of the building blocks.

For more specific information, we refer to Valentin.[5]

[5] Valentin, E. (2001), Reference Manual Airport Passenger Library, TU Delft, faculty of TBM

# 3 Problem Description

In this chapter we will define the problem, the objective of the thesis, the boundary conditions and the requirements of the research.

## 3.1 Problem Description

One of the interesting fields where we could apply simulation, is the field of emergency and evacuation modelling. Terminal buildings should be safe. In case of emergency quick evacuation is necessary to save lives. Not only in case of fire, like at Duesseldorf Airport in 1996, but also if there is another chance on casualties, people will have to be removed from the building, for example when there is a bomb alert, when hostages are taken or when a plane is hijacked. During these situations, airports use terminal evacuation plans with predefined procedures.

Evacuation is a very quick process, during which many decisions have to be taken. It is therefore not easy to describe. The success of evacuation depends on four major factors, namely:

- the emergency and its consequences
- human behaviour in case of emergency
- building characteristics
- management decisions

The factors do not stand alone, but they interact. In the following these factors and their relationships will be illustrated.

### Emergency and its Consequences

The emergency is the first important factor that plays a role. In case of fire, for example, the first complicating factor is the development of smoke, heat and fire itself within the building. This will have impact on the emergency exits available, on the visibility, on the moving velocity et cetera, and therefore on the time needed to clear a building. To describe this factor is rather difficult, because of the many parameters and uncertainties, like for example: the toxicity of the smoke depends on the materials on fire, the smoke density depends on the air conditioning and blowers, the direction of the smoke depends on the draught through the building, et cetera. Other types of emergency have other complicating factors.

### Human behaviour

Humans will react after they notice there is an emergency. Difficulties arise here, when trying to describe human behaviour. Flows of people were often described by means of fluid dynamics models or queuing theory, but recent research shows that this does not necessarily fit the reality[6]. Not all people are the same, and therefore they will act in an unpredictable way. Within airport terminals, for instance, we could easily define different classes of people with different objectives, habits, abilities and tasks, such as tourists,

[6] Helbing, D. (1997); Verkehrsdynamik – Neue Physikalische Modellierungskonzepte, p. 14

business class travellers, escorts and meeters, security personnel, airline personnel et cetera.

In case of emergency they will all act differently. Tourists might want to take their trolleys or heavy luggage with them, while the business class passenger has few luggage and knows exactly how to leave the building safely. Groups of people stay together as long as possible. Firemen and policemen might move in the other direction to fight the fire, while all other people escape from the building. To simulate human behaviour is therefore not always easy. The impact of human behaviour should not be neglected.

### Building characteristics

In case of fire it is necessary to evacuate the people from the terminal buildings. This shows the relevance of well-designed terminals, since a dense concentration of people in a building could lead to many casualties. The design of the terminal affects the way people move through the building and the possibilities they have to escape.

Generally legislation prescribes certain requirements concerning safety and emergency escapes. These rules, like escape distances, number and width of exits, flow capacity of corridors and staircases, and presence of emergency illumination, are usually based upon simple rules of thumb, that are generally not applicable to large and complex buildings where large number of people are gathered[7], such as airport terminals.

Beside this, an important factor is the way passengers are informed and guided in case of emergency. The quality of the emergency illumination, the signs to the emergency exits and the audio signals help people to find their way into safe havens or out of the building. If they do not function correctly, they might guide persons in the wrong direction, for example towards the fire.

Dangerous situations can also be caused by malfunctioning architectural objects. During the fire at Duesseldorf Airport in 1996 for example, people died in an elevator due to malfunctioning of the elevator doors. The elevator's electronical eye detected the dense smoke and refused to close the doors.[8] Also corners or sliding doors may be an objection for quick evacuation.

### Management decisions

The success of evacuation depends also on management decisions. The management board has the power to take decisions that will influence the way of evacuation. These decisions can either be strategic, like the set of requirements to a new terminal design, or operational, like at what specific moment a decision to evacuate should be taken. We can distinguish different fields:

- **Accepted risk – long term**
  It is impossible to design the world in a way that no people die consequent on accidents. We do want to minimise the number of casualties, though. The management can decide to make the terminal design safer, but this does have an impact on the initial investment. The choices in the phase of terminal design

[7] Liew, S. and B. Ashe (2001); Evacuation in Emergency Situations; from: www.nfpa.org/ members/ member_sections/ aviation/ int_l_forum/ liew.pdf
[8] Vlaming, M.J. i.o.v. N.G.M.J. Makker (1996); Definitief intern rapport van de AAS delegatie naar de luchthaven Düsseldorf ter bestudering van de ramp van 11 april 1996 – Ervaringen uit Düsseldorf met beschouwingen naar Schiphol

concerning emergency exits, safe havens, availability of automatic fire extinguishers, et cetera, affect the evacuation.
Another long term management decision is the availability of resources. The fire department and police stations can be expanded, or the management could decide to employ more special emergency crew. Fact is, that one the one hand the airport will be better prepared for emergencies, which will decrease the chance of casualties, but on the other hand this will increase the annual operational costs of the airport drastically.

- **Accepted risk – short term**
  The subject of short term accepted risk is linked to the security of the so called clean area, the area behind the customs and security control. The decision to evacuate people from the clean area has direct consequences and consequences for the period directly after the fire. The direct consequences are that no flights can be executed from this terminal from this moment. Before the terminal can be put into use again, the entire clean area should be checked. This is a very time consuming business with economical impact. In case of alarm the management could decide not to take any risk, and therefore to evacuate the people in the building directly. But they could also decide to wait until they have more information about the severity of the emergency, as this might save money.

## Interactions

As mentioned before, the four different aspects influence one another, which means that they cannot easily be extracted from their context. When describing human behaviour in case of evacuation, we cannot ignore the effects of the construction, the management and the hazard effects. In Figure 3-1 the interactions are sketched schematically.

As the main objective in case of evacuation is to lead the people quick and safe out of the building, the people will be the central focus of this research. Every person present in the terminal building shows his or her specific unique human behaviour. This behaviour, though, is dependent on contextual parameters. First of all, in case of emergency the person will be influenced by hazard effects, such as smoke and the fire, causing both psychological and physiological effects. But in return, this person can affect the emergency, a fire for example by fighting it with fire extinguishers.

Beside this, the persons in the terminal have to deal with the terminal building itself and its construction. In case of emergency the building can guide or mislead people by its signage, offer information through intercom installations, and offer escape routes and safe havens. Next to this information offered by the construction, in case of emergency the management will provide instructions extracted from the evacuation plan.

Furthermore we should not neglect the influences that persons have on each other, by group behaviour, and warning, following, pushing and crushing each other. The interaction between hazard effects on the one hand and the construction on the other hand can be seen as follows. The emergency destroys the building, while the properties of the building (e.g. material use, division of the building in compartments, availability of fire extinguishers and sprinkler installations) are important for the chances the emergency gets to develop, for the toxicity of the possible smoke et cetera.

Finally there are some relations involving the management. They will try to eliminate the fire by executing their fire-fighting plan, informing firemen and other emergency personnel. The relation between construction and management is a special one. The special fire detecting properties of the building offer information to the management, so they can make their operational decisions. The dashed arrow in Figure 3-1, though, is not relevant during the process of evacuation, but it shows the long-term influences of the management on the terminal design. By choosing one design or another the management can determine the safety of the building, by demanding a certain number of escape routes, use of heat resistant materials et cetera.

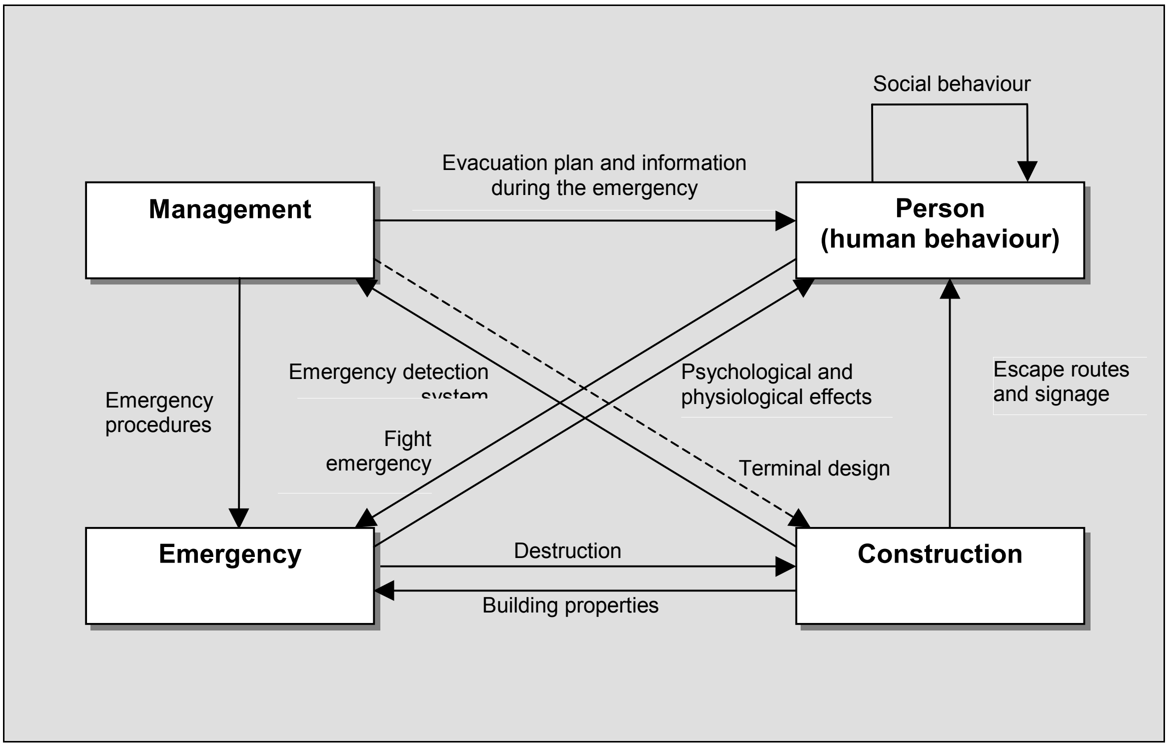


*Figure 3-1: Interactions between the emergency, human behaviour, construction and management decisions in case of evacuation.*

## 3.2 Objective of the Research

This short introduction clarifies that evacuation is a complex subject, with many factors that influence each other in unexpected and unpredictable ways. Using rules of thumb might not lead to the requested level of safety.

Validating terminal architecture and evacuation plans could for example be done by means of real-time evacuation tests, but the effort of such a case study is large and care has to be taken not to cause injuries to the participants. Besides, real time studies can only be executed if the terminal has already been built. The computational methods utilised now are often oversimplified and therefore not very reliable. A compromise between these approaches would be to investigate human motion by means of computer simulation. This tool can close the gap between the behaviour of a single person and the complexity emerging from interactions within a large group and from external circumstances in an emergency situation.[9]

[9] Meyer-König, T., H. Klüpfel, J. Wahle, M. Schreckenberg (2000); Bypass; Assessment and Analysis of Evacuation Processes on Passenger Ships by Microscopic Simulation; paper presented at FP44, International Maritime Institute, February 2000; from: www.traffic.uni-duisburg.de

Simulation could therefore be an ideal tool to assess terminal architecture and evacuation plans, since it is able to deal with the insecurities of unique new concepts and designs of terminal buildings and with an increasing number of passengers.

At the moment the Airport Passenger Library offers the possibility to simulate the normal passenger flows. So far there are no possibilities with this tool to model the passenger flows in case of exceptional events. Since safety is an important matter in today's society, simulation of emergency cases can provide an added value. Therefore the objective of this research will be:

> *Describe the process of evacuation in conceptual models and translate these models into new generic building blocks for the Airport Passenger Library, in order to be able to test the emergency safety of passenger terminal designs.*

This is a very widely defined problem. In the next paragraph the boundaries of this research will be defined more clearly.

## 3.3 Boundary Conditions

Describing the process of evacuation requires insight into the before mentioned different aspects. Because of the limited time available for this thesis, three major boundaries were set to define the system.

- Focus on human behaviour and construction
- Focus on microscopic models
- The existing library is correct

They will be discussed below.

### Focus on human behaviour and construction

This research will focus specifically on the factor of human behaviour in case of emergency and the impact of the construction on this behaviour. This means that for the factors of management decisions, emergency growth and emergency consequences, simple assumptions will be made. In future research it is possible to expand the evacuation model with dynamic smoke and fire models also concerning toxicity and visibility.

Due to this assumption the most important output parameters will be the total evacuation time, the individual evacuation times per passenger and the main bottlenecks.

### Focus on microscopic models

In this research it is assumed that the microscopic view, a simulation of individual groups, is the best way to describe evacuation. This means that no macroscopic view, e.g. fluid dynamics, is taken into account.

### The existing library is correct

It is assumed that the existing building blocks in the Airport Passenger Library, e.g. the blocks that describe the groups, the group generation, the areas, the flight schedule et cetera, have been modelled correctly, and have been verified and validated for normal (non-emergency) situations.

## 3.4 Requirements

The final product of this research, a tool to test the emergency safety of passenger terminal designs, will have to meet certain preliminarily defined requirements. They will be discussed below.

### Representative modelling

The models should be created in a way in which they describe reality. Certain assumptions and simplifications will have to be made, but while modelling one should stay as close to reality as possible. If not, the outcomes will not be representative and are therefore useless.

### Generic objects

The objects describing the evacuation have to be generic. This means that it should be possible to apply them to different airports, without changing the properties of the building blocks.

### Comprehensible user interface

One of the objectives of the Airport Passenger Library is to make it user friendly. Therefore the user interface should be clear.

### Visualisation of the process

In order to make the process of evacuation understandable, a visualisation of the evacuation is required.

### Comprehensible simulation output

The output of the simulation has to be useful and clear.

## 3.5 Research Approach

In order to fulfil the objective of this research, a research plan is constructed. The research plan is schematically presented in Figure 3-2.

After having defined the problem situation in part I of this research, there will be a conceptualisation phase, which consists of literature search and interviews. Goal of this phase, described in Part II and III is to structure the problem situation, to obtain information about the state of the art scientific knowledge on the before mentioned topics.

In the specification and implementation phase (Part IV) the conceptual models will be translated into a simulation model. For this phase a computer and an eM-Plant software license are required. This step will consist of two major processes, namely the simplification of the conceptual models, and the construction of the model.

In the verification phase the new building blocks will be verified. Verification means that the code of the model is checked and compared to the conceptual models.

In the phase of experimentation a real case will be executed, using the existing model of the Schiphol F-pier, in order to see if the model works correctly.

Finally, in Part V, conclusions will be drawn from the results of the experiments, and recommendations will be formulated for future research.

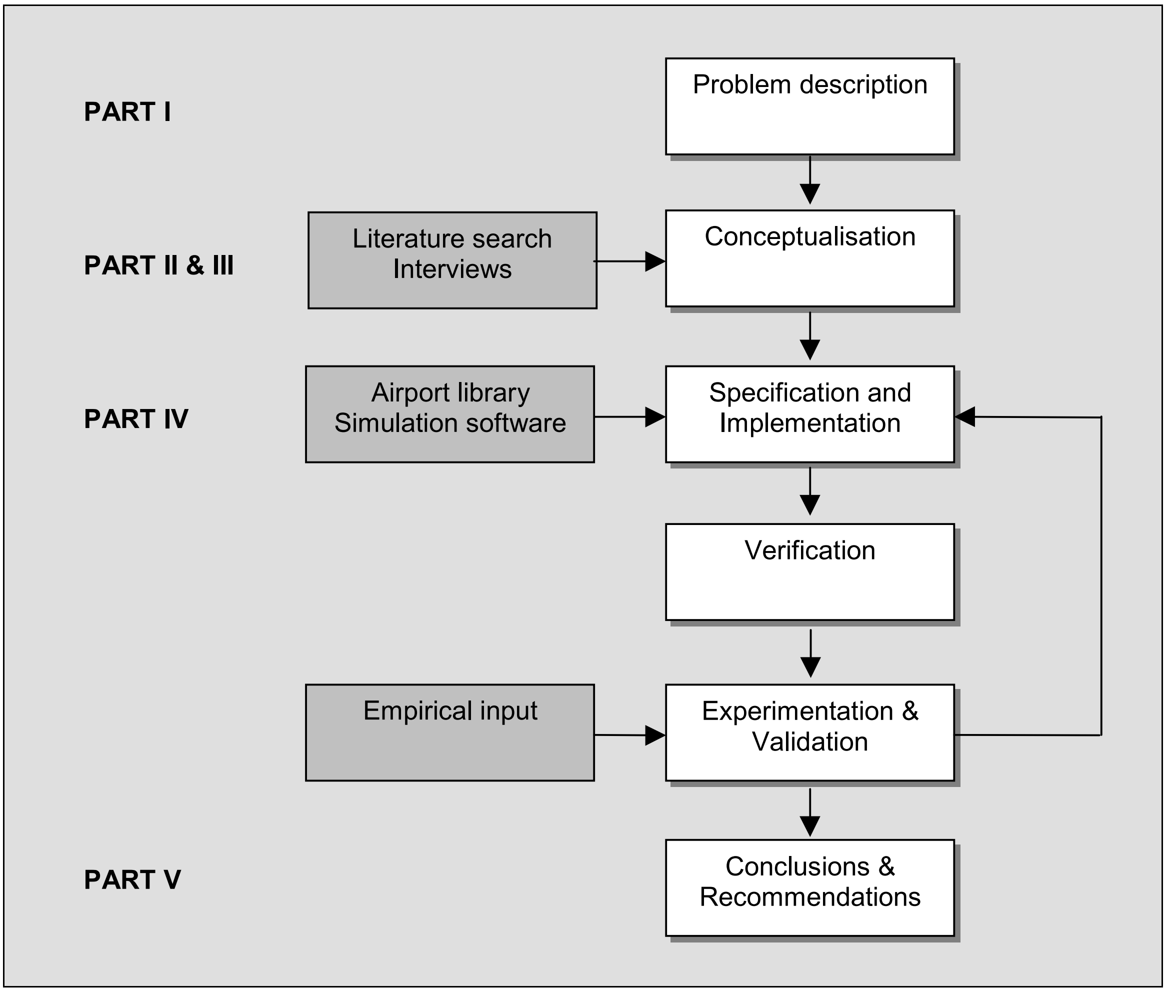


*Figure 3-2: Research approach*

# PART II

# Evacuation and Emergency Theory

# 4 Evacuation and Emergency

In this chapter the concept of evacuation will be made clear. We will define the term and describe the different concepts of evacuation, the different scenarios in which evacuation could be necessary, and how we can decompose the evacuation time. In the subsequent chapters this theory will be deepened.

## *4.1 Evacuation: a Definition*

To evacuate someone means to send him to a place of safety, away from a dangerous building, town, or area.[10] For buildings, we can generally distinguish two evacuation concepts:

- total evacuation
- evacuation to safe havens

Total evacuation is the most common type of evacuation, and means that the entire building is to be cleared and no people are to stay inside. In this case, a place of safety is considered to be a place outside the building.

When is decided to evacuate to safe havens the occupants are guided towards refuges within the building, where they can temporarily stay until the hazard is over. Such a safe haven can for example be a protected corridor or staircase or a place of refuge. Particularly in high-rise buildings, these places of refuge are necessary, since total evacuation of a tall sky-scraper might take two hours or more. Refuge floors may then be provided every six or eight floors up the building.[11] The concept of safe havens, by the way, is used in the United States and Australia, and not common in Europe.

## *4.2 Emergency Situations*

We can distinguish different emergencies in which it could be necessary to evacuate. These situations include[12]:

- Fires and explosions
- Bomb threats
- Terrorism
- Civil disturbance
- Power failure
- Building collapse
- Chemical leaks and spills
- Nerve gas attacks
- Gas leaks
- Flooding
- Earthquakes

[10] Collins Cobuild English Dictionary (1995)
[11] Shields, T.J., and G.W.H. Sitcock (1987); Buildings and Fire; pp. 355-357
[12] Saunders, W. et al. (1996); Human Behaviour in Fire Incidents; Australian National Training Authority and Swinburne University of Technology, p. 3

These different types of emergency have different characteristics and might require different evacuation concepts. During some types of events, like fire or building collapse, the direct life threat is greater than during others, such as power failure. And sometimes, when terrorism plays a role, care has to be taken that no people are kidnapped or shot. Natural disasters such as floods or earthquakes cause other difficulties, due to water or shaking.

Nevertheless, evacuations caused by different types of emergencies do not differ that much. In all cases, all people have to be moved out of the building or towards safe havens as quickly as possible. Some scenarios additionally contain certain non-accessible areas, either because of fire, or because of dangerous armed terrorists, collision danger, toxic chemicals, or water. The number of non-accessible areas can be static, e.g. when during a certain period of time the same part of the building is overlooked by terrorists, or dynamic, e.g. when fire or water is still increasing and occupying more and more of the premises.

*Figure 4-1: Uncommon situations in airport terminals. Due to different types of emergency, evacuations could have to be performed.[13]*

This research will not be limited to fire evacuation. The fact is, though, that most of the evacuation literature deals with fires, and that most emergencies that occur, are fires. As a consequence, fire evacuation is emphasised in this study, but the resulting simulation tool should be able to deal with other emergency types as well.

## 4.3 Evacuation Analysis

To analyse evacuation, we could define the evacuation time of individuals and of a complete building.

### Individual evacuation time

The actual time an occupant of a building requires to evacuate a space to a place of safety, the individual evacuation time, can be divided into the time between the receiving of the cue and the beginning of an occupant's movement, and the time this

[13] Picture taken from: www.hamiltonspectator.com

movement takes. Sime[14] states that this division reflects respectively a crowd psychology emphasis and an engineering emphasis. In formula: [15]

$$(1) \quad t_{\text{evacuation, individual}} = t_{\text{pre-movement}} + t_{\text{movement}}$$

The pre-movement time can be subdivided into recognition time and response time, as can also be seen in Figure 4-2:

$$(2) \quad t_{\text{pre-movement}} = t_{\text{recognition}} + t_{\text{response}}$$

The recognition time is the time between the onset of a cue or condition that is supposed to initiate evacuation, and making the decision to begin movement. This cue could be an announcement or alarm, or a burning object. The response time is the time to prepare to evacuate, and consists for example of investigating other people's behaviour, route choice, getting one's belongings, et cetera.
The problem with many existing simulations and other models is that this pre-movement time is not taken into account, although it can make up a considerable part of the evacuation time.

The movement time on the other hand is the time spent in direct movement toward an exit or place of relative safety. It depends, among others, on the following parameters:

- occupant density
- effective door and corridor width
- travel distance
- travel speed
- converging flows

This will be described more specifically in the next chapters.

It is clear that all occupants do not necessarily have the same pre-movement and movement time. These values can vary per person and per situation, because one's reaction depends on the sort of cue given, individual characteristics, location within the building, et cetera.

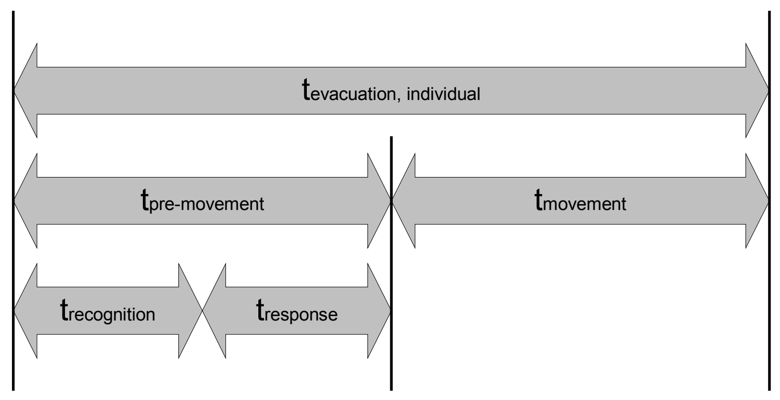


*Figure 4-2: Graphical representation of the individual evacuation time.*

[14] Sime, J.D (1995); Crowd Psychology and Engineering, in: Safety Science 21, pp. 1-14
[15] British Standards Institute (1997); Fire Safety Engineering in Buildings, BSI DD240: Part 1

## Building evacuation time

The building evacuation time is the time to evacuate an entire building, and can be subdivided into the detection time and the time to remove all occupants. It is not easy to distinguish the pre-movement time and the movement time for the entire building as we did for each individual, since the first occupant might have left the building before the last one has even recognised the emergency.

Therefore, we will define the time to remove all occupants as the interval between (1) the moment the last evacuee leaves the building, and (2) the moment the first evacuee receives a cue. In formula:

$$(3) \qquad t_{evacuation,\ building} = t_{detection} + (T_{exit\ last\ evacuee} - T_{cue\ first\ evacuee})$$

The detection time is the time between an incident starts and the moment of the first cue given to the occupants. It depends, among others, on the following components:

- the type of emergency
- the gravity of the emergency
- the number and quality of detectors, e.g. fire detectors
- the organisational structure during emergencies
- the warning system in the building

# 5 Simulation and Evacuation

In this chapter we will present characteristics of and differences among the state of the art evacuation simulation tools developed until now. After this, in the second part of this chapter, we will present the TU Delft Airport Passenger Library and its characteristics.

## 5.1 *Existing Tools for Simulating Emergency Evacuation*

There are different ways to judge the safety of the built environment by means of egress computer models. Gwynne e.a.[16] summarise the history of evacuation modelling, naming and evaluating the large range of existing quantitatively-oriented models. They divide these models roughly into two categories: (1) models that only consider human movement, treating persons as non-thinking objects that respond automatically to external stimuli, and (2) models that attempt to link movement with human behaviour, describing persons as active agents with individual characteristics.

The article focuses on four characteristics of the different evacuation models, namely the nature of model application, the enclosure representation, the population perspective and the behaviour perspective. They will be discussed below.

### Nature of model application

Gwynne et al. distinguish three main approaches: optimisation, simulation, and risk assessment. The optimisation models assume that the occupants evacuate in as efficient a manner as possible, ignoring peripheral and non-evacuation activities. The routes chosen are optimal, as are the flow characteristics of people and exits. The simulation models take into account human behaviour in order to realistically represent the paths and decisions taken during an evacuation. The authors warn that the behavioural sophistication employed by the models and therefore the accuracy of the results varies greatly. Finally, the risk assessment models attempt to identify hazards associated with evacuation resulting from a fire or related incident and attempt to quantify risk. By performing repeated runs, variations associated with changes to the geometric design can be assessed.

### Enclosure representation

A description of the enclosure in which the evacuation takes place is an obligatory input for all models. There are two ways to represent the network: by using a fine network or a coarse network. In the fine network approach, the entire floor space of the enclosure is usually covered in a collection of nodes and tiles, which sizes and connections to other tiles vary from model to model. These models offer the possibility to represent the geometry very accurately and to locate the individual occupants during the simulation. The coarse network approach defines the geometry more roughly, on a higher level of scale, with each node being for example a room or a corridor. Occupants move from segment to segment, and their precise position within this segment is less defined. In the latter case, Gwynne et al. foresee problems with presenting local movement,

[16] Gwynne, S., E.R. Galea, M. Owen, P.J. Lawrence, L. Filippidis (1999); A Review of the Methodologies Used in the Computer Simulation of Evacuation from the Built Environment; in: Building and Environment 34, pp. 741-749

overtaking and obstacle avoidance, because detailed calculations of individual movement and the interactions between individuals cannot be made. However, coarse networks have the advantage in the ease of representation and the speed of computation.

### Population perspective

The population can be represented according to an individual or a global perspective. In the individual perspective, personal characteristics are assigned to the occupants, either by the user, or by a random generator. These characteristics determine the individual behaviour. The global perspective treats the population as a homogeneous group, not recognising individuals. This approach works generally with distributions and average behaviour, which presents difficulties in modelling the effects on individual occupants, e.g. the effect of toxic gasses. It cannot show which occupants escaped, but only how many occupants.

### Behaviour perspective

In order to describe the process of individual decision making in the evacuation models, Gwynne et al. define the following behavioural systems:

- no behaviour rules
- functional analogy behaviour
- implicit behaviour
- rule based behavioural system
- artificial intelligence based behavioural system

The models with no behavioural rules are based fully on physical movement of people, without incorporating individual behaviour.

Using functional analogy behaviour can be seen as implementing an equation or a set of equations that govern the population's response. All individuals are affected the same way by this function, for example by using physical magnetic theory to describe movement.

Models that do not declare behavioural rules but instead assume them to be implicitly represented through the use of complicated physical methods, apply implicit behaviour. These models might be based on the application of secondary data, which incorporates psychological or sociological influences.

Within a rule based behavioural system, occupants take decisions based on explicit pre-defined rules that are triggered in certain circumstances. An example of such a rule is: ,,If I am in a smoke filled room, I will leave through the nearest available exit.'' In order not to take always the same decision in the same circumstances, most rule-based models are stochastic.

In artificial intelligence based behavioural systems, individual occupants mimic human intelligence, or an approximation of it, in respect to the surrounding environment.

### Overview

In Figure 5-1 the existing simulation tools observed by Gwynne et al. are situated in a diagram, showing their characteristics. The authors of the article observed a trend towards models that include greater behavioural detail. According to them, the effect of more behavioural detail is decreasing when coarse networks or a global perspective are adopted. They favour fine networks and an individual perspective, since this provides the possibility to identify individuals, their positions, and their interactions.

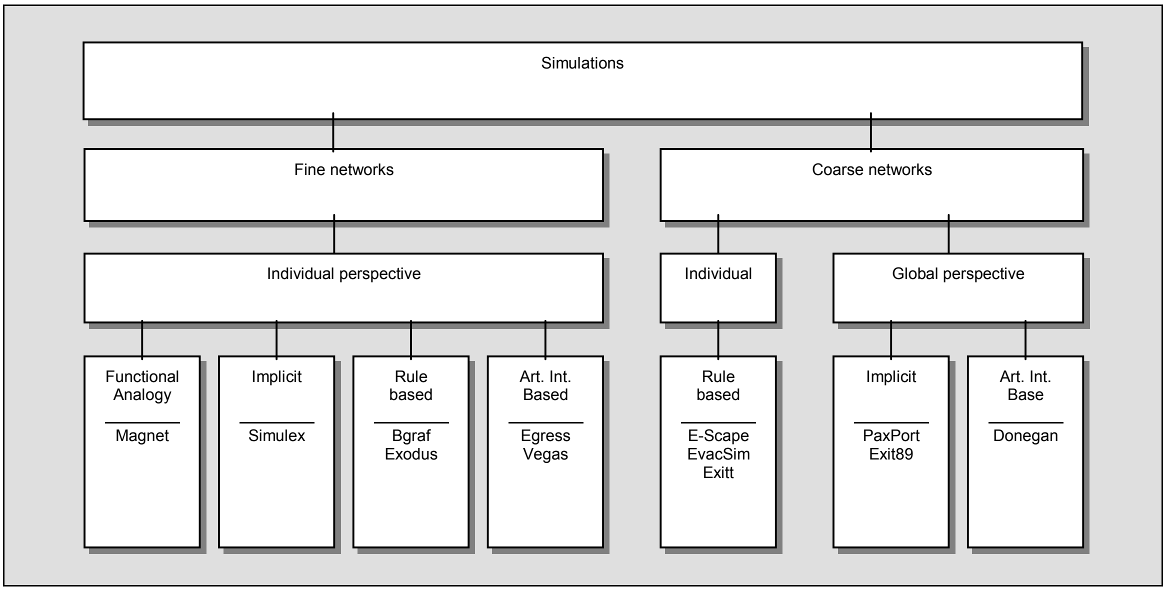


*Figure 5-1: Diagram representing evacuation simulation tools (Gwynne e.a., 1999)*

## Problems

It is evident that not all relevant factors are taken into account in the existing simulation tools. Therefore, care should be taken when interpreting the outcomes of model runs. In most cases an absolute conclusion like

> *'The evacuation of this building will take 3 minutes and 35 seconds'*

drawn from the simulation output is not acceptable, because simplifications have been made. For instance, some models suppose that the occupants of a building always choose the nearest exit, others do not calculate a pre-movement time. Generally, the factors not taken into account will in reality cause even longer evacuation times. This has a major impact on the outcomes of the simulation, which are therefore mostly underestimated evacuation times.

It would be better to formulate the conclusions of model runs in a relative way, like

> *'The evacuation time of layout A is 20% longer than the evacuation time of layout B under the same circumstances.'*

Beside this, it is possible to play 'political' games using black box simulation studies. Changing relevant parameters values can mislead decision makers that do not have simulation skills or complete insight into the models.

Consequently, Van de Leur[17] states that simulation can be a very dangerous tool when used by incompetent or not-reliable persons. In practice simulation results can be found that are completely non-realistic. He suggests that many results coming from state of

[17] Van de Leur, P.H.E.; TNO Centre for Fire Research; interview June 6th, 2001

the art tools should be multiplied by some safety factor, representing the not (yet) quantifiable aspects.

## 5.2 *Airport Passenger Library*

Before the evacuation facility can be implemented in the existing Airport Passenger Library, it is important to define the properties of the existing simulation tools. In the following, the Airport Passenger Library[18] will be analysed using the above mentioned characteristics.

### Coarse network

The Airport Passenger Library that will be used in this research consists of a coarse network. The different spaces of the airport terminal are represented by building blocks called 'areas'. The area object is an object that provides a group with a location to stay. Every group needs at least one area to accommodate it. There are building blocks for:

- walking areas
- sitting areas
- leisure areas
- conveyer belts
- elevators
- security control
- check-in desks
- et cetera.

In the simulation, the terminal layout can be constructed by connecting these objects. The occupants move through the terminal by entering and leaving the objects. Generally, area objects can be seen as resources to be claimed by the occupants. The time the occupants need to move through an object is determined by the character of the object. Check-in desks and security control objects have certain process times and capacities, while the time to walk through walking areas depends on walking distances, represented by a resistance parameter, walking speed, and current density. When the occupant is ready with its task within one object, it can claim access to the next object. Whether the occupant is admitted to this next object depends on the availability of this object. Every object has a certain capacity, which is specified by means of the size of the surface or the number of persons or groups of persons it can contain at the same time.

### Individual perspective

The occupants are represented by 'group' objects. A group is a set of one or more passengers staying together while going through the airport. The model can therefore be defined as adopting an individual perspective. Currently, the following are the main attributes of the groups, registered within the simulation:

- area where the group currently stays
- destination of the group, as determined in the script
- number of persons in the group
- scripts currently under execution
- size of the surface the group occupies

[18] Valentin, E. (2000); Airport Passenger Library User Guide, concept

- maximum walking speed in a normal walk area
- moment the group entered the current area
- time until the group needs to start walking to reach its final destination

The groups are created by the 'group generator' object, which generates the groups on a desired moment and a desired location, based on a given flight schedule and on the type of passenger. Tourists will for example generally arrive earlier than business passengers, because they might not know the terminal layout very well or they would like to do some tax-free shopping. At the moment of generation, groups are given certain attributes.

Currently, only passengers are modelled in the Airport Passenger Library. Some personnel like check-in desk or security personnel are included in the model, but just as resource capacity within the objects. They do not 'come out of their office' and move as a group, which means they do not have impact on the movement of the groups. We will come back on this matter later in this research.

## Rule based behaviour

The Group Control object controls the activities of the groups. This object requests area capacity, arranges arrivals and departure from areas, and interprets scripts. The occupants within the terminal building behave according to rules. One of those rules might be

> *'If there is enough time left before departure, I will do some shopping.'*

The sequence of activities performed is initially determined at the moment of creation by the group generator and is only changed during the simulation run, when a certain condition is fulfilled. In that case, the script will be changed. Rule-based behaviour can therefore be considered deterministic. During the normal day-to-day terminal processes, for which the TUD Airport Passenger Library was initially developed, the individual behaviour of occupants is less relevant than during emergencies.

An important notion is the absence of individual route choice behaviour. Occupants always use the shortest path towards their destination. Not using the shortest path can be implemented by inserting sub-destinations or by closing certain paths by artificially increasing their resistance.

It is possible, though, to implement more behaviour, for example by making new occupants' destinations depend on a combination of triggering events, individual characteristics, and stochastic distributions.

## Conclusions

At the moment the Airport Passenger Library consists of a coarse network, individual perspective and rule-based behaviour. Within this model, we will start implementing an emergency and evacuation tool.

# 6 Building Characteristics

Differences in behaviour can occur due to particular physical details of the design of the buildings involved. Characteristics of the building should be known in order to be able to determine the movement time of the occupants through the building. In this research we will focus on the characteristics that have influence on the movement of the occupants, and not on the parts of the construction that deal with the detection of emergencies (e.g. smoke detectors) and the fighting of emergencies (e.g. sprinkler installations).

- Walkways and stairs
- Doors
- Lighting and emergency lighting
- Building layout and signage
- Emergency cues

## 6.1 *Walkways and Stairs*

The dimensions of the walkways, doorways and stairs play a significant role in the movement time of individuals, since only a certain number of passengers can pass at the same time. The specific flow $F_s$ (in persons per metre per second) can be estimated using the following formula:[19-20]

$$(1) \qquad F_s = S * D$$

where S is the speed, and D is the density of the passing persons. The density can be defined as the number of persons divided by the available escape route area pertinent to the space where the persons are originally located, in persons per square metres.

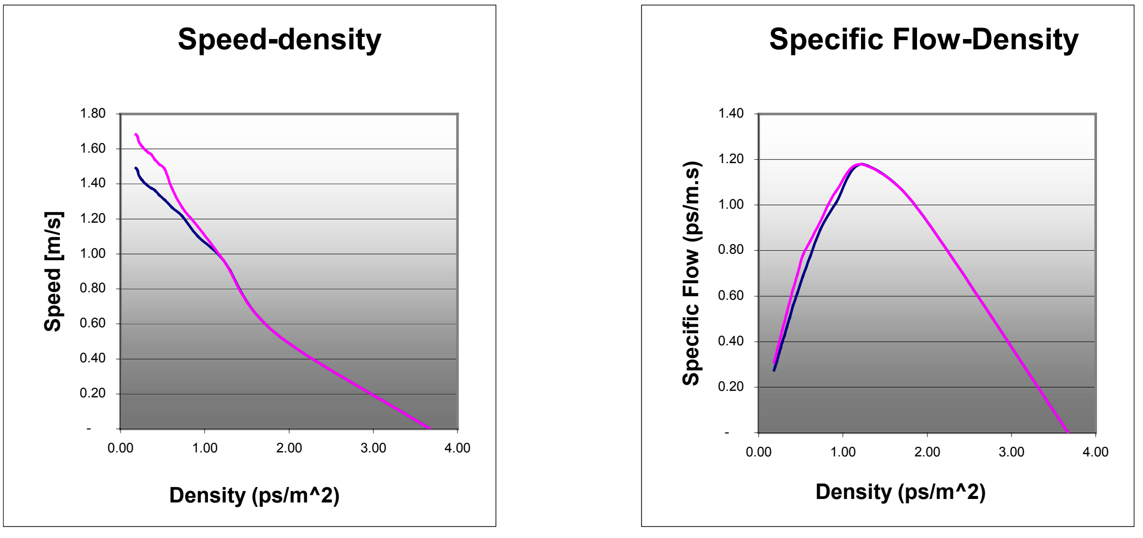


*Figure 6-1: Schematic view of speed-density diagram (left) and specific flow-density diagram, as used in the Airport Passenger Library. Taken from Fruin.[21]*

[19] Stichting Bouwresearch (1984); Menselijk Gedrag bij Brand, publicatie B29-2, pp. 104-119
[20] IMO (1999); Interim Guidelines for a Simplified Evacuation Analysis on Ro-ro Passenger Ships
[21] Fruin Ph.D., John J. (1971); Pedestrian Planning and Design

If the density is low (for walking speeds with a maximum of 1,6 m/s this is a density lower than 0,8 persons per square metre), a person is able to walk with any speed. As soon as there are more people on the same walkway, there will be interaction between them. People have to adapt their speed to the speed of others. If the space between two people decreases – i.e. a higher density appears – the step-size will get smaller and the speed decreases too: speed and density are related, as can be seen in Figure 6-1. With a density of about 5,5 persons per square metre no further movement is possible. The maximum specific flow, about 1,9 persons per metre per second, occurs when the combination of speed and density is optimal.

*Table 6-1: Values for specific flow on stairs and on level surface (in persons per meter width per second) recommended for design of emergency egress routes. Taken from Graat et al.*[22]

| Source | Stairs | Level | Subject |
|---|---|---|---|
| London Transport Board (1958) | 1.11 | | London Underground |
| Hankin and Wright (1958) | ↑ 1.04<br>↓ 1.15 | 1.48 | London Underground |
| Fruin (1971) | 0.93 | 1.37 | Walkways (indoors and outdoors) |
| Predtetschenski and Milinski (1971) | ↑ 1.23<br>↓ 1.21 | 1.66 | Unknown |
| General Services Administration (1972) | ↑ 1.11<br>↓ 1.25 | 1.67 | Unknown |
| Poyner et al. (1972) | | 1.42<br>1.82-1.92 | Soccer stadium<br>Unknown |
| Melinek and Booth (1975) | 1.10 | 1.80 | Unknown |
| Tregenza (1976) | 1.00 | 1.40 | Unknown |
| Neufert (1980) | 1.25 | | Olympic stadium Amsterdam |
| Pauls and Jones (1980) | 0.99 | | High rise office building |
| Pauls (1980) | ↑ 1.25<br>↓ 1.18 | | Office building >800 persons<br>Office building <800 persons |
| NFPA (1983) NFPA 130 | 1.19 | | Subway |
| The Aqua Group (1984) | | 1.50 | Unknown |
| Stichting Bouwresearch (1984b) | 1.28 | 1.88 | London Underground (LTB, 1958) |
| van Bogaert (1986) | ↑ 1.50<br>↓ 1.83 | 2.50 | School |
| Ando et al. (1988) | ↑ 1.21<br>↓ 1.48 | 1.67 | Japanese Railway stations |
| NFPA (1988) | 0.83 | 1.33 | |
| Pauls (1988) | 1.34<br>1.25<br>1.21<br>0.79 | 1.79<br><br>1.82<br> | High rise office buildings (USA)<br>(UK)<br>(UK, traditional)<br>(Australia) |
| Guide to Safety at Sports Grounds (Green Guide, 1990) | 1.21 | 1.82 | Unknown (for purpose of Calculation only) |
| Appraisal of Sports Grounds (1991) | 1.21<br>0.79 | 1.82<br>1.12 | Unknown (emergencies)<br>Unknown (normal conditions) |
| British Standards Institute (1991) BS 5588 part 2 +6 +10 | 1.33 | 1.33 | Shopping centres and meeting places |
| Daly et al. (1991) | ↑ 1.03<br>↓ 1.14 | 1.43 | Subway |
| Templer (1992) | 1.03 | 1.26-1.42 | Commuters and stadium (Fruin, 1970) |
| Cunningham and Cullen (1993) | ↑ 1.04<br>↓ 1.15 | 1.48 | Unknown |
| Thompson and Marchant (1995) | | 1.80<br>(1.50-2.0) | Computer simulation (SIMULEX) |

The calculated flow of persons $F_c$, or the number of people that pass an element in the egress route per second can be described as follows:

$$(2) \qquad F_c = F_s * W_e$$

where the effective width $W_e$ is the width that is actually used by the occupants. Due to a certain distance people maintain from a wall, the effective width can be calculated by taking the absolute width and subtracting 0,15 m for each adjoining wall, and 0,089 m for each wall with a handrail.

Scientists do not yet agree on the values of the different parameters. Different studies have tried to determine the specific flow of stairs and level surface in persons per meter width per second. Graat et al.[22] composed a table with different values taken from about thirty different studies, showing that the results vary significantly: from 1.12 for normal conditions in the Appraisal of Sports Grounds to 2.5 for school buildings in fires. In table 6.1 we will present these data.

## 6.2 Doors

Doors in walkways may cause congestion. Like for walkways, for doors we can determine a specific flow. The Foundation for Building Research has compiled the evacuation capacities of door openings from different studies. These data are presented in Table 6-2. The effective width of doors is equal to the absolute width, as the entire door will be used. Different authors give different values for specific flow. In our model we will use the default value of 1.5, recommended by the Dutch building code.

It is also important to take into account the situation on the other side of the door. Congestion may be caused by stored goods, tables and chairs, or a corridor in which other flows of people are confronted. Even people who do not move away from the exit once they feel safe, for example due to bad weather conditions[23], can cause congestion, sometimes with terrible consequences.

In general, emergency exits should look 'attractive' to the escaping person. It should provide a positive perspective of safety, a 'promising' route.[24]

*Table 6-2: Evacuation specific flow of door openings per metre width and per second.*

| **Way of evacuation** | **Specific flow** *(p / m.s)* |
|---|---|
| 1 – Slow and comfortable | 1.2 |
| 2 – Normal | 2.4 |
| 3 – Crowding at small doors ≤ 1.2 m | 3.0 * |
| 4 – Crowding at wide doors > 1.2 m | 4.8 ** |
| * arch-shaped crowding probable<br>** falling and stumbling probable | |

Source: Foundation for Building Research[25]

[22] Graat, E., C. Midden, P. Bockholts (1999); Complex Evacuation; Effects of Motivation Level and Slope of Stairs on Emergency Egress Time in a Sports Stadium; in: Safety Science 31 (1999), pp. 127-141

[23] Gwynne, S., E.R. Galea, P.J. Lawrence, M. Owen, L. Filippidis (1998); A Systematic Comparison of Model Predictions Produced by the BuildingExodus Evacuation Model and the Tsukuba Pavilion Evacuation Data; in: Journal of Applied Science, Vol. 7, No. 3, pp.235-266

[24] Boer, L.C. (2001); Way-finding Behaviour and Guidance Systems; paper presented at the International Conference on Emergency Management, Oslo, June 2001

## 6.3 Lighting and Emergency Lighting

The extent of lighting in the building, either special emergency lighting and normal lighting has influence on the ease of escape. It is therefore interesting to know if some lighting has backup power facilities when the normal supply fails. The emergency lighting system provides illumination to enable the occupants to move around in the building properly and to indicate the available escape routes.[26]

## 6.4 Building Layout and Signage

In evacuation time calculations and simulations it is often presumed that the occupants know exactly which escape route is the shortest and best. This assumption is not realistic. People do not have an overview and tend to use the exit they used when entering the building, and not the closest exit.

The architecture of the building plays an important role in the way-finding of people. The layout and the position of objects and walls should in some way be able to give directional information; moving towards the daylight means in such a case for example moving towards an exit. Clear architecture is an advantage in case of evacuation. Concerning airport terminals it should be noted that inhomogeneous growth has often negative influence on the clarity and therefore on the orientation of people within the building.

Wenzel[27] states that signage is required only there where the necessary directional information is not provided by the architecture itself. Galea[28] means that enclosure itself can assist in the way-finding process by presenting a simple memorable landscape around which to navigate.

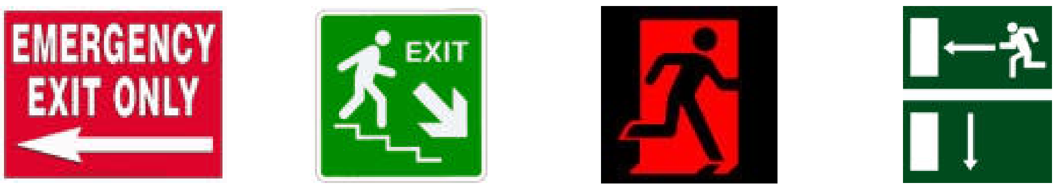


*Figure 6-2: Signage is an important factor in way-finding.*

Way-finding can be improved by appropriate signage in the building. Signage is used to aide way-finding, and should provide the occupant with enough, appropriate, and unambiguous information to minimise the time spent on way-finding. In danger, however persons might oversee signage. Boer[29] states that signs and maps are important, as they make the invisible visible. The emotional state of the occupants, though, can influence their ability to notice the signs. Anxious passengers will mind only the obvious signs, and will not have patience to study maps or decipher complicated directions and instructions.

[25] Stichting Bouwresearch (1984); Menselijk Gedrag bij Brand, publicatie B29-2, pp. 104-119
[26] Shields, T.J., and G.W.H. Silcock (1987); Buildings and Fire; pp. 379-380
[27] Wenzel, Dr.-Ing. P. (1999); Fußgänger-Leitsysteme – Planung von Leitsystemen in Fußgänger-Verkehrsanlagen am Beispiel von Fluggast-Empfangsgebäuden; p.21
[28] Galea, E.R., M. Owen, S. Gwynne (1999); Principles and Practice of Evacuation Modelling – A Collection of Lecture Notes for a Short Course; 2nd Edition
[29] Boer, L.C. (2001); Way-finding Behaviour and Guidance Systems; paper presented at the International Conference on Emergency Management, Oslo, June 2001

It is clear that the visibility of the emergency exits and escape routes has a great impact on the human behaviour. If an exit is not clearly indicated, it might not be used by the occupants, causing additional delays in egress. Signs should be obvious and conspicuous, and they should not be accompanied by items that can distract the attention from the emergency signs, such as advertisements. Obviously, the presence of smoke has impact on the visibility of signage.

Concluding, we could say that it is very hard to assess the visibility of escape routes quantitatively. Besides, this visibility might even be seen as a dynamic parameter, changing during emergencies such as fire. This will cause difficulties when simulating egress behaviour.

## 6.5 *Emergency Cues*

It is important to note that a building or setting is not only a physical space or structure, but an information system through which people move, states Sime.[30] The cues people receive during an emergency determine the initial behaviour and the pre-movement time. The success of a cue depends mainly on two factors, namely the clarity of the warning and the believability of the warning.[31] People can receive different types of cues, for example:

- Cues due to direct interaction with the emergency.
- Alarms and alarm systems.
- Public address systems with spoken messages.
- Social communications and warnings, such as instructions by building personnel or other persons.

The cues due to direct interaction with an emergency can for example be a confrontation with smoke, fire, noises, terrorists, power failure, water, et cetera. Although it might seem apparent that people will attempt to flee once they have noticed an emergency, the truth is that they often continue doing their normal activities, or even approach the emergency to see what is going on.

The problem with alarm systems such as bells, sirens, flashing lights, and electronic tones is that they do not offer information to the occupants. Before escaping people might lose valuable time looking for confirmation. Beside this people are ‘trained’ to ignore alarm systems, because the amount of false alarms is higher than the amount of real alarms.

Public address systems offer spoken messages to the public about an emergency. The messages can be divided into directive and non-directive announcements, where the directive announcements contain specific information on the emergency and the direction in which occupants should move. This way people can be given precise instructions on the varying conditions, and no time is wasted looking for confirmation or determining an appropriate course of action.[32]

[30] Sime, J.D. (1995); Crowd Psychology and Engineering; in: Safety Science 21, pp. 1-14
[31] Galea, E.R., M. Owen, S. Gwynne (1999); Principles and Practice of Evacuation Modelling – A Collection of Lecture Notes for a Short Course; 2nd Edition
[32] Saunders, W. et al. (1996); Human Behaviour in Fire Incidents; Australian National Training Authority and Swinburne University of Technology, pp. 48-53

Social communications and warnings can either be given by an authority person, or by people of the general public. Canter shows[33] that there can be a difference in perception depending on the roles and responsibilities of the person giving instructions. During the King's Cross fire in the London underground station people tended to follow the instruction of Police officers, whereas the instructions given by some of the members of the public and underground staff were ignored by the travellers.

Proulx and Sime[34] show with their study on the evacuation of an underground station that very different evacuation times and patterns of behaviour can be achieved in the same physical setting by altering the information available to people about a potential danger.

Table 6-3, taken from their study, shows the times it took a dispersed crowd to leave a Newcastle underground station. During the five different experiments different cues or combinations of cues were given to the participants. In the first experiment there was just an alarm bell. In the other experiments, staff, non-directive public announcements and directive announcements were added in different combinations. The non-directive announcements did not contain further information about which direction to go, whereas the directive announcements gave instructions based on watching a closed circuit TV system in the control centre.

The results in this table show clearly that the way the occupants are informed has a significant impact on the pre-movement time. When using a bell only, as in the first scenario, people tend to ignore the alarm bell and continue their journeys. The second, fourth and fifth scenarios show the best results, as people are directed to a safe place, either by staff or by spoken messages. The total evacuation times were reduced by at least 50%, mainly by reducing the time for people to start to move (the pre-movement time).

The factor of information, although hard to quantify, cannot be neglected when performing simulations.

*Table 6-3: Times of crowd movement in five evacuations of an underground station (in minutes and seconds).*

| Evacuation scenario | Time to start to move | | Time to clear the station | Appropriateness of behaviour |
|---|---|---|---|---|
| | *Concourse* | *Bottom of escalator* | | |
| 1 – Bell | 8.15 | 9.00 | 14.47 | Delayed or no evacuation |
| 2 – Bell and staff | 2.15 | 3.00 | 8.00 | Users directed to concourse |
| 3 – Bell and non-directive P.A. | 1.15 | 7.40 | 10.30 | Users stood at bottom of escalator |
| 4 – Bell, staff and directive P.A | 1.15 | 1.30 | 6.45 | Users evacuated |
| 5 – Bell and directive P.A. | 1.30 | 1.00 | 5.45 | Users evacuated by trains and exits |

Source: Proulx and Sime[35]

[33] Canter, D. (ed., 1990); Fires and Human Behaviour – second edition; p. 27
[34] Proulx, G. and J.D. Sime (1991); To Prevent Panic in an Underground Emergency: Why not tell People the Truth?; in: G. Cox and B. Langford (eds.), Fire Safety Science: Third International Symposium, pp. 843-852
[35] Proulx, G. and J.D. Sime (1991); To Prevent Panic in an Underground Emergency: Why not tell People the Truth?; in: G. Cox and B. Langford (eds.), Fire Safety Science: Third International Symposium, pp. 849

# 7 Human Behaviour during Emergencies

How do human beings behave in case of emergency? That is the question to which we should know the answer if we want to simulate emergency egress. In this chapter a general overview of the literature on human behaviour in emergencies will be given, starting with the difficulties of studying human behaviour. Then we will introduce Canter's model of human behaviour in fire, followed by a paragraph on the most important human characteristics that have impact on behaviour in case of emergency. Finally, we conclude with some theory about the behavioural change due to emergency and the concept of panic.

## 7.1 *Studying Emergency Behaviour*

In order to be able to simulate human behaviour, quantitative data should be gained. This is not an easy task. There are different ways to obtain knowledge about human behaviour:

- Real emergencies
- Announced evacuation exercises
- Unannounced evacuation exercises

First, real emergencies can be analysed. But problems appear soon. Canter[36], whose research focuses mainly on fires, gives a few reasons for this. First of all, emergencies – fortunately – do not occur very often. But not only are they rare, they are also unpredictable, which makes it almost impossible to monitor them properly from beginning to end. Besides, not all people who experienced a disaster can be questioned about their behaviour, either because they suffer emotional damage, or because they are killed or badly injured by the fire.

Evacuation exercises can supply further knowledge. Two different types of experiments can be distinguished: announced evacuation exercises with volunteers and unannounced evacuation, in which occupants are not informed in advance. A big advantage is that scientists can prepare the experiments, and it is possible to use video cameras to register the movements of the occupants in a very precise way.

Nevertheless, exercises are not a perfect way to gather data. During an announced evacuation, performed by e.g. Klüpfel et al.[37], people know in advance that they are supposed to leave the building, which means that firstly they have time to prepare and secondly they know there is no real life threatening danger. This will highly influence the evacuation behaviour of the occupants.

Unannounced evacuations, as carried out by for example Shields and Boyce[38], cause ethical problems. Is it right to subject people to the physical and emotional stresses produced by emergency situations in laboratory experiments? The consequences of

[36] Canter, D. (ed., 1990); Fires and Human Behaviour – second edition; pp. 5-9
[37] Klüpfel, H., T. Meyer-König, M. Schreckenberg (2000); Evakuierungsübung und Vergleich mit Simulationsergebnissen – Saal eines Multiplex-Kinos; University of Duisburg
[38] Shields, T.J. and K.E. Boyce (2000); A Study of Evacuation from Large Retail Stores; in: Fire Safety Journal 35, pp. 25-49

such an exercise might be serious, since for example injuries can be obtained during the flight.[39] That is why few unannounced evacuations have been carried out.

### Methodology

The three most common methods to register the information is by using:

- Questionnaires
- Interviews
- Video footage

Questionnaire studies and direct interviews with survivors and firemen after real emergencies and participants and firemen during exercises provide interesting information, but also leave questions. Besides, people might tend to reveal cleaned versions of reality, not mentioning things or changing stories in order not to seem guilty.[40] The use of video footages would give the most specific information, such as the exact pre-movement times and walking routes of the occupants. The problem, though, is that footages are not always available in case of real emergencies, either because there was no registration, or because legal authorities forbid their scientific use.

Beside these problems, there is also the financial consequence of carrying out real-time experiments. The organisation of such experiments is rather expensive, especially when video equipment is used that should cover the entire building. The results of a single experiment are not necessarily useful, since it is recommended to repeat experiments several times before trusting the results.

## 7.2 *Canter's Model of Human Behaviour in Fire*

In his studies on human behaviour in fires, Canter[41] defines a number of identifiable stages, with different routes from one stage to another. The action sequence in the model is derived from British data. In summary, according to this model, the human behaviour in fires is seen as follows:

- The individual receives initial cues and investigates or misinterprets these initial cues.
- Once the fire is apparent, the individual will try to obtain further information, contact others or leave.
- Thereafter the individual will deal with the fire, interact with others or escape.

This can be translated into five broad stages, as showed in Figure 7-1. It should be mentioned that the further the fire develops, the more difficult it is to predict the behaviour of the individuals and the more likely it is that the occupancy of the individual plays a significant role in his behaviour. In the following the different stages will be discussed in more detail.

[39] Saunders, W. et al. (1996); Human Behaviour in Fire Incidents; Australian National Training Authority and Swinburne University of Technology, pp. 10-11
[40] Dombrowsky, W.R. (1988); Verhalten von Menschen bei Bränden – Technische Determinanten de Verhaltens bei Bränden – Einladung zum Umdenken; Arbeitsgemeinschaft der Innenministerien der Bundesländer – Arbeitskreis V – Unterausschuß "Feuerwehrangelegenheiten"
[41] Canter, D. (ed., 1990); Fires and Human Behaviour – second edition; p. 134

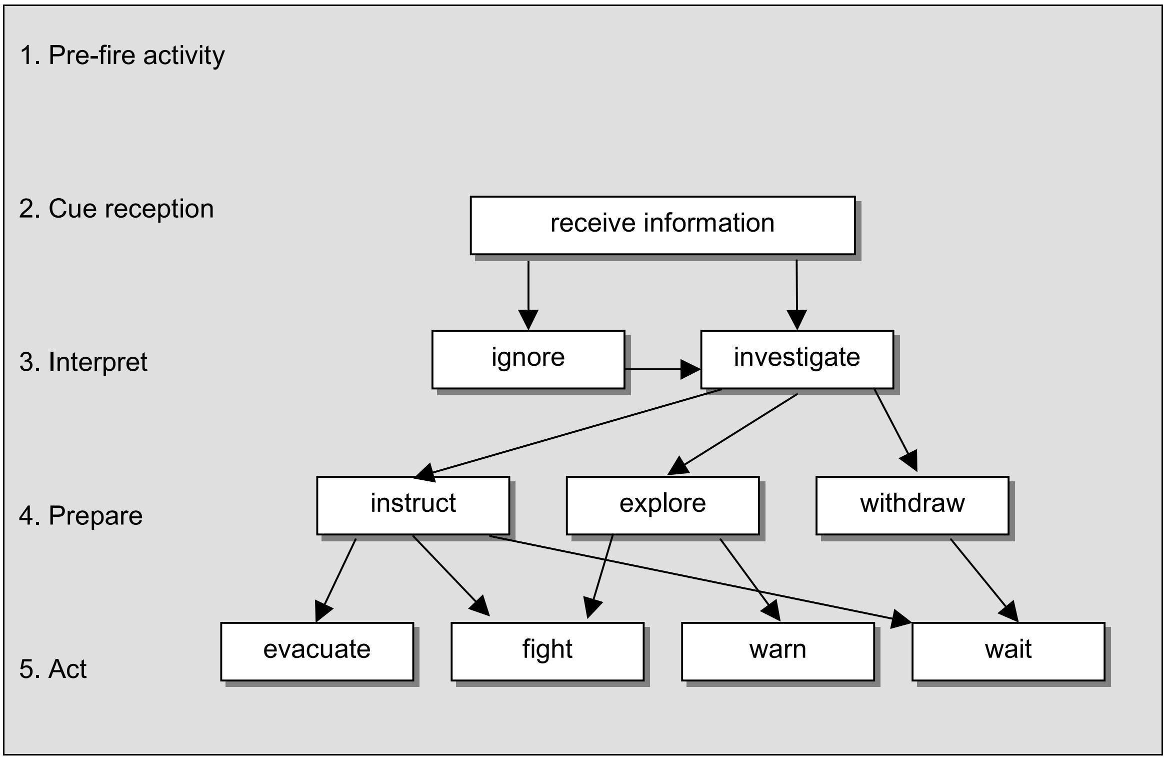


*Figure 7-1: Canter's model of human behaviour in fire.*[42]

## Pre-fire activity

Canter emphasises the importance of the pre-fire activity in predicting subsequent actions. This activity determines the alertness of and the social influences on the occupant, and will therefore affect the recognition of the cues.

## Cue reception

Cue reception might be a function of pre-fire activity, role and responsibility assumed in the situation and ambiguity of the cues. A person engaged in an activity with a well-known action sequence, such as eating in a restaurant, might interpret the cues differently, which influences the subsequent behaviour. People tend to ignore the signals they receive, due to the ambiguity of the cues. In most cases it is not instantly clear what happens, how dangerous this is and what the individual should do to avoid getting hurt. More detailed information on the different possible cues one could receive is given later in this chapter.

## Interpret

The interpretation of the often ambiguous cues can lead to either a full conception of the situation, or to a misconception. Since people will act on their *personal* definition of the situation, their behaviour will depend on whether the occupant has conceived the information correctly. The response of people will be affected by the assumption that other people are in charge and have the situation under control.

[42] Canter, D. (ed., 1990); Fires and Human Behaviour – second edition; p. 134, p. 226

**Prepare**

Canter distinguishes in this phase the possibility to instruct, explore or withdraw. The existing role in an organisation determines whether the persons will 'instruct' during fires. The 'explore' stage consists of various activities concerning establishing exactly what is happening, e.g. going towards the fire. 'Withdraw' behaviour is most typical for hotel fires, where occupants behave in a context of privacy and self-reliance.

**Act**

The behaviour in this stage depends upon role, occupancy, earlier behaviour and experience. Men are more likely to fight the fire than women, hotel guests are likely to wait. The decision by employees to fire fight the fire or evacuate is determined, among others, by the hierarchy within an organisation and the instructions given by superiors.

**Canter's model for emergencies**

In the context of emergencies in general, an interesting question would be, whether this model of human behaviour during fires can be applied to other emergencies. Dombrowsky[43] states that behaviour during earthquakes is similar to behaviour in fires. People for example tend to get dressed before leaving the house, or go back into the affected building or area although it is not safe.

The phases ignore, investigate, instruct, explore, withdraw, evacuate, fight, warn and wait do not specifically refer to fires. In this research, therefore, we assume that Canter's model is also valid for other emergencies, although some phases might not be appropriate to each emergency. We could have doubts about the meaning of 'fighting' an earthquake, but this could consist of preventing buildings to collapse.

## 7.3 *Human Characteristics Influencing Behaviour*

Canter's model describes the possible behavioural types of occupants in a fire. It does not show by what personal characteristics certain behaviour is stimulated. This information, however, is important when we want to predict the behaviour of airport terminal occupants. Therefore it is necessary to know what personal individual aspects are of importance in case of an emergency evacuation.

Ideally, we could distinguish temporary conditions, long term conditions and permanent factors. It is not easy though, to divide the characteristics over these categories. A physical disability such as a broken leg may be considered long term, but a paralysis is mostly a permanent condition. Psychological disabilities might be permanent, but of no importance since the attacks only appear temporarily.

The following categories of individual characteristics are found in the literature.[44-45] Some categories might partly overlap, like for example age and physical disabilities, and physical disabilities and dependence. Elderly people are more likely to have difficulties in hearing, seeing or moving.

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[43] Dombrowsky, W.R. (1988); Verhalten von Menschen bei Bränden – Technische Determinanten de Verhaltens bei Bränden – Einladung zum Umdenken; Arbeitsgemeinschaft der Innenministerien der Bundesländer – Arbeitskreis V – Unterausschuß "Feuerwehrangelegenheiten", p. 25

[44] Saunders, W. et al. (1996); Human Behaviour in Fire Incidents; Australian National Training Authority and Swinburne University of Technology, pp. 22-26

[45] Sandberg, A. (1997); Unannounced Evacuation of Large Retail-stores – An Evaluation of Human Behaviour and Computer Model Simulex; Department of Fire Safety Engineering, Lund University

### Gender

Interpretation of signals and chosen responses may depend on the gender of an occupant. Research by Wood[46] shows that women appear to be more concerned with the safety of people, in that they are more likely to warn others and evacuate family and themselves. Men seem to be more situation-orientated, being more likely to attempt fire fighting or minimise the risk. They are also more likely to return into the building and move into smoke.

### Age

The age of an occupant can affect the ability to detect, interpret and respond to an emergency. Children might for example be completely dependent upon their parents, and elderly might have problems hearing the signals and moving quickly through the building.

*Figure 7-2: People with disabilities have more difficulties during evacuations. At Singapore Changi Airport, special service by ground handling agents is available.[47]*

### Physical disabilities

Some occupants might be physically disabled. Blindness or deafness can cause troubles detecting the emergency signals, while restricted movement gives problems escaping quickly. During movement, physically disabled people often depend on the assistance of others, especially when elevators and escalators are out of order because of the emergency. Due to their disability, people respond differently. A person in a wheelchair will not escape directly, but he will search people to help him to escape.

Airline passengers with lots of baggage can also be considered physically disabled, because their ability to move is restricted as long as they refuse to leave their belongings behind in case of emergency.

During emergencies the size of the disabled population in the building might increase due to hazard effects.

### Psychological disabilities, personality, mood

People suffering from psychological disabilities might exaggerate, ignore or understate emergency signals. Anxiety or depression can influence the way in which an individual

[46] Wood, Peter G. (1980); A Survey of Behaviour in Fires, in: Canter (1990, ed.), pp. 83-95
[47] Pictures taken from: http://www.dpa.org.sg

interprets the situation and the choices available. Personal characteristics such as risk taking or predisposition to anxiety and mood at the time of emergency can have similar effects on decision making. Psychological disabilities and personality can be seen as reasonably permanent personal attributes, whereas the mood state may be a temporal condition.

## Training, experience and education

Training, experience and education of the occupant can influence recognition, interpretation and response to an emergency. Awareness of the hazards, following a familiar plan of action learnt during a training and familiarity with the equipment to deal with the emergency can reduce the time necessary to think about the next action. Beside this, trained procedures will give confidence to the occupants, since they know that the action they take is accurate.



*Figure 7-3: Language skills are important during evacuations. Knowledge of the language enables occupants to understand signage and spoken messages.*

## Language skills

If spoken instructions are given during emergencies, it is important that people are able to understand these instructions. Not being capable of understanding the written and spoken messages might increase the response time in case of emergency, and limit the way-finding capacities of the occupant.[48] People who do not understand the messages will tend to follow others once they know there is something wrong.

## Alertness and state of consciousness

The ability to recognise, interpret or respond to an emergency depends highly on the alertness of an occupant. The alertness can be reduced by the use of medication, drugs, or alcohol. Alcohol for example acts as a central nervous system depressant slowing reactions and distorting perception. Other drugs might produce hallucinations, causing inability to distinguish between reality and the person's distorted mental picture of it. Areas like restaurants, bars, discotheques and concert halls have an increased risk.

Whether a person is awake or asleep has a similar influence on his perception. Many fatalities in residential buildings occur because the occupants are asleep when the fire

[48] Van de Leur, P.H.E.; TNO Centre for Fire Research; interview June 6th, 2001

starts. Toxic by-products of the fires, gas leaks and chemical spills can also affect consciousness and the ability to detect and respond to danger.

### Independence and dependence

Some people are dependent on others, like children in schools and kindergarten, patients in hospitals and other institutions, or prisoners in prison. Warning signs are generally given only to those in charge, because the dependent people are incapable of emergency decision making, either because of their young age, or because of mobility limitations.

### Roles, rules and responsibility

An individual's role is a pattern of behaviour consisting of certain rights, obligations and duties, given to him through his position in an organisation or social context. One's role can for example be 'manager of a company', 'patient in a hospital' or 'father'. Role and responsibility affect the decision making, because due to his position a person can be held responsible for the safety of others. Confusion can occur when people fail to fulfil their role in case of emergency. On the other hand, individuals who are trained in particular skills, such as doctors, fire fighters and nurses might even take responsibility when they are off duty.

### Affiliation

Affiliation is the attachment of individuals to the familiar. Sime[49] developed a model that found that people under threat head for the familiar. Firstly, this can be other people, such as family members, colleagues, or friends. Evacuation of groups can be delayed when group members are separated, because they start searching each other instead of the exit. Secondly people tend to go back to familiar places, such as previously used entrances or their own hotel room, and thirdly they look for familiar situations or role patterns.

### Current position

Of major importance is the current position of the occupant in a building. The closer someone is to a safe haven or emergency exit, the fewer problems could appear on his way. The proximity to the threat also determines the potential danger to the individual and his possibilities to flight. Beside this, the audibility and visibility of signals may vary from place to place. In other cases signals can be misinterpreted: in a restaurant a smell of smoke coming from the kitchen might not be considered dangerous by a client, because some smoke is considered to be normal there. Finally, if a person is lying, sitting, or standing might have influence on the willingness to move and might increase the movement time.[50]

### Individual walking speed

The speed with which a person moves through the building is called the individual walking speed. The normal walking speed in an open space is 1.2 to 1.5 meters per second. In different settings, for example between rows of seats, or when the density of

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[49] Sime, J.D. (1985); The Outcome of Escape Behaviour in the Summerland Fire: Panic or Affiliation?, in: Proceedings of the International Conference on Building Use and Safety Technology, National Intstitute of Building Sciences.

[50] Sime, J.D. (1995); Crowd Psychology and Engineering; in: Safety Science 21, pp. 1-14

people increases, the walking speed is less. Walking speed depends highly on physical disabilities, age, gender, and number of luggage pieces. In groups, the walking speed generally depends on the slowest group member.[51]

### Commitment to activity

Occupants might have a strong commitment to the activities they perform in a building. This commitment can be caused by an expected order of events. In a restaurant for example, it is normal first to order food, then to eat the food, and finally pay the bill and leave. People are 'trained' to follow this sequence of activities, and consider it strange to leave without completing all tasks. This might cause a delay in case of emergency, because alarms are ignored. Almost the same psychological concept can be seen when people are in a queue, for example waiting at a check in desk in an airport terminal. They are not very eager to leave their position in the queue, because they conclude that this will probably lead to longer waiting times. People sometimes tend to complete their activity before responding to an alarm.[52]

### Focal point

The recognition time can increase when the attention of the occupants goes to a central activity. In football stadiums for instance the game can attract people's attention, so they tend to ignore emergency signals or react with a certain time delay.

### Characteristics summary

In Table 7-1, the before mentioned factors are listed and summarised. In the columns is defined whether a factor has influence on a person's capacity to recognise the alarm (and therefore on the recognition time and indirectly on the pre-movement time), to interpret the alarm correctly and to respond to the alarm and choose an act to perform. This impact can either have a positive or a negative impact on the recognition time, the ability to interpret or to respond.

It should be noted, however, that not all of these characteristics have tangible measures or benchmarks against which to make an assessment.[53] It is therefore not easy to provide the occupants of an airport terminal with a quantitative value on each characteristic. Assessing alertness or language skills on a one to ten scale is rather difficult, if not impossible.

## *7.4 Behavioural Changes due to Danger*

Certain reflexes occur due to the perception of a sudden dangerous situation, since the individual knows he should act properly in order to survive. These reflexes are both physiological effects, like an increase in adrenaline secretion, an increase in heart rate and blood pressure, an increase of respiration, et cetera, and emotional effects such as stress, fear and anxiety. The level of emotional tension depends on one's individual perception of the danger. Previous experiences and training usually decrease this tension.

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[51] Gwynne, S., E.R. Galea, P.J. Lawrence, M. Owen, L. Filippidis (1998); A Systematic Comparison of Model Predictions Produced by the BuildingExodus Evacuation Model and the Tsukuba Pavilion Evacuation Data; in: Journal of Applied Science, Vol. 7, No. 3, pp.235-266

[52] Sime, J.D. (1995); Crowd Psychology and Engineering; in: Safety Science 21, pp. 1-14

[53] Shields, T.J. and K.E. Boyce (2000); A Study of Evacuation from Large Retail Stores; in: Fire Safety Journal 35, pp. 25-49

*Table 7-1: What characteristics have influence on respectively recognition, interpretation and response?*

| Characteristic | Recognition Time | Interpretation of the signal | Response act |
|---|---|---|---|
| Gender | | ♦ | ♦ |
| Age | ♦ | ♦ | ♦ |
| Physical disabilities | ♦ | | ♦ |
| Psychological disabilities, personality, mood | ♦ | ♦ | ♦ |
| Training, experience, education | ♦ | ♦ | ♦ |
| Language skills | ♦ | ♦ | ♦ |
| Alertness, state of consciousness | ♦ | ♦ | ♦ |
| Independence and dependence | ♦ | | ♦ |
| Roles, rules and responsibility | | | ♦ |
| Affiliation | | | ♦ |
| Current position | ♦ | ♦ | ♦ |
| Individual walking speed | | | |
| Commitment to activity | ♦ | ♦ | ♦ |
| Focal point | ♦ | | |

As a consequence of the physiological and emotional effects, we can notice behavioural changes. Saunders et al.[54] distinguish both changes of individual behaviour and group behaviour. The individual behavioural changes can consist of:

- **Narrowing of attention**
  The narrowing of attention or tunnel vision makes the individual focus on a narrow range of signs. It is therefore more likely he will miss important cues and have difficulties absorbing the available information.
- **Hasty decision making**
  An individual in danger experiences time pressure, which makes him nervous, since he feels no time is available to consider all possibilities. There is a tendency to make a decision quickly, though this might not offer the best solution.
- **Limited manual dexterity**
  Due to physiological changes like shaking and trembling, one loses the full co-ordination of his muscles, which leads to clumsiness and affects the ability to do fine motor tasks.

## 7.5 Group Behaviour

Concerning group behaviour Saunders et al. distinguish positive social factors and negative social factors. Positive social factors appear when members of a group support each other during an emergency, while negative factors cause disruption and in extreme cases may result in selfishness or panic. The presence of other people can lead to the following situations.

- **Conformity**
  The actions of others are imitated and the occupant acts differently from the way he would have acted alone.
- **Social facilitation**
  This is the influence of the presence of others on the performance of tasks. Easy tasks are generally performed in a better way, while difficult tasks are performed worse.

[54] Saunders, W. et al. (1996); Human Behaviour in Fire Incidents; Australian National Training Authority and Swinburne University of Technology, pp. 39-45

- **Social loafing**
  Social loafing is the withdrawal of a person from his or her personal responsibilities because of reliance on the efforts of others.
- **The social trap**
  The social trap is a situation in which many persons claim the use of a specific resource that is not sufficient for all. The result might as well be the loss of the entire resource. Traps like this lead to extreme selfish behaviour, which can be seen at emergency exits, when people fight for quick egress.
- **The risky shift**
  A risky shift is the tendency for people in groups to take bigger risks in collective decision making than they would have done as individuals. Individuals are persuaded by the majority to change their opinion.

There are also positive factors, though. Boer[55] concludes in his studies on evacuation of cruise ships that groups show better way-finding behaviour than individuals. He explains this, referring to the concept of error correction of groups. Group members follow each other, and if one member makes a mistake, the others will try to correct him. The probability that both group member one and group member two make a mistake is simply smaller than the probability that a single individual makes a mistake.

## 7.6 Panic

Panic can be defined as a demoralising terror and a sudden loss of self control that leads to frantic action and highly emotional behaviour. This is produced by an immediate and severe threat of danger to oneself and/or others.[56]

Quarantelli[57] assumes that the following conditions are necessary for panic to occur:

- The persons are not yet trapped, but they feel they are going to be trapped unless someone does something about it.
- The persons have a sense of inability to do something about getting out of the threatening situation.
- The persons feel completely alone in resolving their dilemma, since they cannot count on help from others and must cope with the crisis by themselves.

It is often supposed that people in serious danger such as in fires, tend to irrational behaviour and panic. Sime[58] states, though, that the concept of panic is often mistaken for any form of flight behaviour. Since flight is not the normal way of leaving a building, it might look more disorganised than it is. In fact, behaviour can be called irrational when an individual does not take into account all the alternative possibilities of which he can be aware. The present problem is that panic is often mistaken for any ineffective behaviour. If one is not aware of an alternative route, his rational behaviour will be to try to save his life using the known egress possibilities. If the actions the individual takes are likely to be unfortunate, like for example jumping, blockage at an exit, escape

[55] Boer, L.C. (2001); Way-finding Behaviour and Guidance Systems; paper presented at the International Conference on Emergency Management, Oslo, June 2001
[56] Saunders, W. et al. (1996); Human Behaviour in Fire Incidents; Australian National Training Authority and Swinburne University of Technology, pp. 11
[57] Quarantelli, E.L. (1977); Panic Behaviour: Some Empirical Observations; in: Conway, D.J. (1977, ed.), Human Response to Tall Buildings
[58] Sime, J.D. (1990); The Concept of Panic; in: Canter (1990, ed.), pp. 63-81

without family members, people tend to refer to the situation as irrational. Turner and Killian[59] describe it clearly:

> *,,When people, attempting to escape from a burning building pile up at a single exit, their behaviour appears highly irrational to someone who learns after the panic that other exits were available. To the actor in the situation who does not recognise the existence of these alternatives, attempting to flight his way to the only exit available may seem a very logical choice as opposed to burning to death."*

Sime[60] confirms this. He states that orderly egress becomes impossible if people are to have a chance of surviving. Flight is almost invariably rational in circumstances where people are warned too late and have limited knowledge of the layout of a complex setting.

[59] Turner, R.H. and L.M. Killian (1957); Collective Behaviour
[60] Sime, J.D. (1995); Crowd Psychology and Engineering; in: Safety Science 21, pp. 1-14

# 8 Conclusions Evacuation and Emergency Theory

## 8.1 *Evacuation and Emergency*

- Different types of emergency have different characteristics and might require different evacuation concepts.
- To analyse evacuation, we could define the evacuation time of individuals and of a complete building.
- Simulation models can be categorised according to four major characteristics, namely the nature of model application, the enclosure representation, the population perspective and the behaviour perspective. At the moment the Airport Passenger Library consists of a coarse network, individual perspective and rule-based behaviour. The question at this moment is whether these characteristics of a simulation tool offer a good base for evacuation modelling.

## 8.2 *Building characteristics*

- Differences in behaviour can occur due to particular physical details of the design of the buildings involved. The relevant factors are walkways and stairs, doors, lighting and emergency lighting, building layout and signage, and emergency cues
- Scientists do not yet agree on the values of the different parameters, such as flows through walkways and doors under specific densities. It is also important to take into account the situation on the other side of the door, since for example bad weather conditions can cause congestion
- In general, emergency exits should look ‘attractive’ to the escaping person. Doors that provide a positive perspective of safety or a ‘promising’ route will attract more people.
- The extent of lighting in the building, either special emergency lighting and normal lighting has influence on the ease of escape
- People do not have an overview and tend to use the exit they used when entering the building, and not the closest exit. The architecture of the building and the signage plays an important role in the way-finding of people. In danger, however signage might be overseen by persons.
- Problem is, that it is very hard to assess the visibility of escape routes quantitatively. Besides, this visibility might change during an emergency.
- The cues people receive during an emergency determine the initial behaviour and the pre-movement time. The success of a cue depends mainly on two factors, namely the clarity of the warning and the believability of the warning.

## 8.3 *Human behaviour in an emergency*

- If we want to simulate emergency egress, we will have to know which behaviour people show in case of an emergency.
- From Canter’s model of human behaviour in fire we can derive the following action sequence:
  1. The individual receives initial cues and investigates or misinterprets these initial cues.
  2. Once the fire is apparent, the individual will try to obtain further information, contact others or leave.

3. Thereafter the individual will deal with the fire, interact with others or escape.

- The pre-fire activity is an important factor in predicting subsequent actions. The pre-movement time depends partly upon this, and influences reception of the cues and the interpretation of these cues. Initial cues tend to be ambiguous, and therefore people look for confirmation.
- It is necessary to know what personal individual aspects are of importance in case of an emergency evacuation. The most important characteristics are affiliation, the current position, the individual walking speed, and the commitment to an activity
- The presence of other people influences behaviour. Both positive social factors and negative social factors can be distinguished. Positive social factors appear when members of a group support each other during an emergency, while negative factors cause disruption and in extreme cases may result in selfishness or panic.
- Since flight is not the normal way of leaving a building, it might look more disorganised than it is. Flight behaviour is often mistaken for panic.
- We also found that human behaviour during emergencies is influenced by individual characteristics, such as gender, age, physical disabilities, psychological disabilities, personality, mood, training, experience, education, language skills, alertness, state of consciousness, independence, dependence, roles, rules, responsibility, affiliation, current position, commitment to the current activity and focal point. These characteristics have impact on recognition time, interpretation or response, or a combination of these.

# PART III

# Theory applied to airport terminal buildings

# 9 Airport Terminals: Building Characteristics

As mentioned in chapter 7, major differences in behaviour are not due to variations between the personalities of the people present, but to particular physical details of the design of the physical environment involved. Therefore, in this chapter we will have a look on the type of place that is subject in this study: the airport terminal. We will focus on the following:

- airport terminal: definition
- areas and processes
- terminal layouts
- occupants and their characteristics
- emergency behaviour in airport terminals

The first three topics will be discussed in this chapter, the latter two in the subsequent. First of all airport terminals will be introduced with their general characteristics and different appearances. Then we will zoom in on the particular areas within terminals and the activities performed in these areas.

| | Passenger terminal system | | |
|---|---|---|---|
| | **Access interface** | **Processing system** | **Flight interface** |
| **Activity** | Enplaning<br>Deplaning<br>Parking<br>Circulating | Ticketing<br>Checking in luggage<br>Checking passport<br>Claiming luggage<br>Checking customs | Assembling<br>Waiting<br>Loading<br>Unloading |
| **Physical facility** | Enplaning at curb<br>Deplaning at curb<br>Parking garage<br>Transit platform | Ticket counter<br>Luggage deposit<br>Passport counter<br>Bag claim device<br>Customs counter | Hold room<br>Waiting lounge<br>Mobile lounge<br>Bus<br>Jetway<br>Stair / ramp |

*Figure 9-1: Main components of the passenger terminal system.*[61]

## 9.1 *Airport Terminal: a Definition*

The airport terminal can be seen as the connection between the airside and the landside. It includes the facilities for passenger and luggage processing, cargo handling (although mostly in separate cargo terminals), and airport maintenance, operations and administration activities.

According to Horonjeff and McKelvey[62] three components of passenger terminals can be distinguished: the access interface, the processing system and the flight interface. The access interface is the place where the passenger transfers from his or her access

[61] based upon: Horonjeff, R. and F.X. McKelvey (1994); Planning & Design of Airports; fourth edition, pp. 435

[62] Horonjeff, R. and F.X. McKelvey (1994); Planning & Design of Airports; fourth edition, pp. 431-479

mode of travel to the next component, the passenger processing system. The access interface consists of loading and unloading positions for vehicles, parking facilities, walkways and roadway connections to and from the terminal building, et cetera. The main components of the passenger terminal building are schematically shown in Figure 9-1.

The processing system is the system that prepares the passenger for starting, ending or continuing his air transportation trip, including for example ticket purchase, luggage check-in, luggage claim, seat assignment, custom inspections, and security. The processing system also contains non-public facilities, such as truck service docks, food preparation areas, luggage processing, storage, and airport administration and management. A process model for the passenger can be found in Appendix I.

The flight interface connects the terminal to the parked aircraft on the apron. Activities such as boarding, assembly, passenger conveyance to and from the aircraft, and aircraft loading and unloading are performed here.

In order to design a user-friendly and efficient terminal building, Edwards[63] mentions the basic criteria for terminal design:

- easy orientation for the travelling public
- shortest possible walking distances
- minimum level changes
- avoidance of passenger cross-flows
- built-in flexibility
- separation of arriving and departing passengers

We could add to the list a new, but nevertheless very important criterion:

- safe and quick evacuation in case of emergency

## 9.2 *Areas and Processes*

The behaviour performed in case of emergency depends highly on the area in which the occupant is located. The behaviour depends both on the physical location and properties of the area, and on the current activity performed within the area. The pre-movement time in case of emergency, for example, depends highly on the activity an individual performs. Therefore it is interesting to register per area and per process if there is a high commitment to an activity or a chance that events occur that might obstruct or stimulate quick recognition or movement. Beside this, it would be good to know which areas are sensitive to fire or other types of emergency.

In order to obtain more insight in the importance of areas and processes we will analyse some recent emergencies in airport terminals. Then we zoom in on the general terminal layout, where we will distinguish the different areas within the terminal. Within these areas specific processes are performed. The areas and the respective activities performed within this area will be schematically summed up, added with the most important emergency topics related to this area. Beside this, the impact of the area and the process on emergency behaviour will be mentioned.[64-65]

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[63] Edwards, B. (1998); The Modern Terminal – New approaches to Airport Architecture
[64] Ashford, N. and P.H. Wright (1992); Airport Engineering – third edition; p. 306
[65] Horonjeff, R. and F.X. McKelvey (1994); Planning & Design of Airports; fourth edition, pp. 448-464

This research will be limited to the public areas of the terminal, which means that areas such as administrative offices, baggage handling, cabin services and aircraft maintenance will be omitted.

## Recent airport terminal emergencies

It is interesting to define the specifically emergency sensitive areas and activities. Since this could have impact on evacuation scenarios, some of the recent emergencies, mainly fires within terminal buildings are analysed. Note that this list is not a complete review on all recent terminal emergencies, it just shows the diverse appearances of emergencies.[66]

- **Colombo International Airport – July 24th, 2001[67]**
  The Liberation Tigers of Tamil Eelam attacked the Colombo International Airport and destroyed both commercial and military aircraft. Several military personnel were killed in the attack, military and airport employees were injured, and civilians were caught in the crossfire.
- **Amsterdam Airport Schiphol – April 8th, 2001[68]**
  A fire broke out in the kitchen of the Burger King restaurant in Schiphol Plaza. Soon after the alarm the fire was under control. Sparks of this fire, via the extractor fan of the restaurant, probably caused the fire on the top floors and roof of the office tower of Terminal West. This fire caused heavy smoke.
- **Calcutta Airport – February 10th, 2001**
  Near an immigration counter, a policeman shot two of his colleagues to death and injured two other policemen. The officer later turned the gun on himself.
- **Amsterdam Airport Schiphol – January 18th, 2001[69]**
  A fire ignited by a homeless person and shortly afterwards an explosion took place in a public toilet in an arrival hall. The arrival halls and the shopping centre were evacuated because of the large amount of smoke.
- **Delhi Indira Gandhi Airport – December 14th, 2000[70]**
  Two minor fires broke out in the terminal building, delaying several flights. According to an airport spokesman the first was caused by a short-circuit in the men's toilet of terminal 1B. After the power was switched on again, a new sparkling in the cables in the false ceiling of the Sahara Airways office appeared. Both fires were quickly controlled and did not cause damage.
- **Chicago O'Hare Airport – August 26th, 1999[71]**
  A man passed from the luggage claim area to the security control without being checked, which forced the airline management to evacuate over 6000 people from the terminal, although it was unknown whether the man was a terrorist or a hasty passenger. At least 120 flights were cancelled. No bombs or guns were found. (See Figure 9-2)
- **London Gatwick Airport – February 1st, 1998[72]**
  Staff and customers were evacuated from the Burger King restaurant in the north terminal, where a fry station caught fire. Passengers in this part of the terminal were guided to other parts. No flights were delayed.

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66 Emergency and Disaster Management Inc. (2001); Airport Incidents; at: www.emergency-management.net/airport

67 CNN.com (2001); Sri Lanka airport reopens ; on: http://www.cnn.com

68 Schiphol Group (2001); Situation at Schiphol Airport back to Normal; at: www.schiphol.nl, Press Release April 8th, 2001

69 Schiphol Group (2001); Operations at Schiphol Airport Almost to Normal; at: www.schiphol.nl, Press Release January 18th, 2001

70 The Hindu (2000); Fire at Delhi Airport Terminal; at: www.indiaserver.com/thehindu

71 Chicago Tribune (1999); O'Hare Evacuation Snarls Air Travel Across U.S.; at: www.chicagotribune.com

72 The Catering Net (1998); Burger King Restaurant Fire at Gatwick Airport; at: www.cateringnet.co.uk

- **London Heathrow Airport – December 12th, 1997**[73]
  A smoky fire above a deep-fat fryer at a Heathrow Airport Burger King in terminal one. It disrupted hundreds of flights and caused delays to over fifty thousand passengers.
- **Duesseldorf Airport – April 11th, 1996**[74]
  A fire started in the void above the ground-floor ceiling and spread to upper levels. Investigators believe that a welder caused the ignition. Sixteen people died, eight of them were trapped in an Air France VIP lounge where the voice annunciation system was turned off, and seven of them were trapped in elevators that could not close their doors due to smoke. Another 62 people were injured.
- **Vienna Airport – December 27th, 1985**
  Three terrorists entered a departure lounge, throwing grenades and firing from automatic weapons at an El Al[75] counter. Two people were killed, 39 sustained injuries.
- **Rome Airport – December 27th, 1985**
  Three terrorists entered a cafeteria, opened fire and hurled hand grenades in the El Al passenger section, where 15 people died and 70 were injured.
- **New York La Guardia Airport – December 29th, 1975**
  A bomb exploded in a locker area of the main terminal, causing 75 injuries and 11 deaths.

Not many conclusions can be drawn from this list, apart from the fact that there seems to be an increased chance of fires in restaurant areas.


*Figure 9-2: Thousands of passengers gather in front of O'Hare International Airport at United Airlines terminal 1, after the area was closed by police to search for a man who breached security.*[76]

## Areas and processes

The processes within an airport terminal can be split into primary and secondary processes. The primary processes are those related to the passenger and luggage transhipment from landside to airside and vice versa. Secondary processes are not directly related to the transport functionality of the airport, but provide the passengers with additional services, for example entertainment.

[73] Lubbock Avalanche-Journal (1997); Fat Fire Delays Flights in U.K.; at: www.lubbockonline.com
[74] Wolf, A. (1996); Seventeen Die in Duesseldorf Airport Terminal Fire; in: NFPA Journal, July/August 1996
[75] El Al is the Israeli national carrier.
[76] Picture taken from: www.chicagotribune.com, photo by George Thompson

The primary processes are schematically listed in Table 9-1. Especially the waiting queues generated at some locations might cause increased pre-movement times. Beside this, it must be noted that some areas are generally not accessible, such as the apron, or only accessible after a certain procedure, such as a passport check (Figure 9-3). During emergencies, this might be a barrier to some occupants, which causes the time to escape to increase.

*Table 9-1: Primary areas and processes within an airport terminal*

| Area | Process | Emergency topic |
|---|---|---|
| Curbs - loading and unloading | Loading vehicle<br>Unloading vehicle<br>Greeting | • Passengers still possess all their luggage, and are probably not willing to leave this behind in case of emergency. |
| Entryways, foyers, lobby | Entering terminal<br>Leaving terminal<br>Obtaining information<br>Walking<br>Visitor waiting | • Passengers still possess all their luggage, and are probably not willing to leave this behind in case of emergency.<br>• In case of bad weather conditions, the entryways might be blocked because people prefer shelter over open air. |
| Airline ticket counters | Ticket purchase<br>Queuing | • People in long queues might not easily want to give up their position. |
| Check-in desks | Checking in<br>Queuing<br>Greeting | • People in long queues might not easily want to give up their position.<br>• Passengers still possess all their luggage, and are probably not willing to leave this behind in case of emergency. |
| Security | Security check<br>Queuing | • People in long queues might not easily want to give up their position.<br>• In case of emergency, passing the security might be an objection, since it is not allowed in normal situations.<br>• This might be a bottleneck when people try to return to the place where they came from. |
| Customs and immigration services | Checking passport<br>Checking luggage<br>Queuing | • People in long queues might not easily want to give up their position.<br>• In case of emergency passing the customs might be an objection, since it is not allowed in normal situations.<br>• This might be a bottleneck when people try to return to the place where they came from. |
| Luggage claim | Waiting<br>Claiming luggage | • People want to wait for their belongings.<br>• Baggage trolleys might avoid quick movement or obstruct the exits.<br>• People might tend to pass the customs to get out, because this is the normal procedure. They might oversee the emergency exits. |
| Arrival lobby | Meeting<br>Meeter waiting | • Passengers possess all their luggage, and are probably not willing to leave this behind in case of emergency. |
| Departure lounges | Waiting<br>Boarding<br>Queuing | • People in long queues might not easily want to give up their position.<br>• Since entering the apron is normally forbidden, this might keep occupants from doing so in case of emergency. |
| Bridges | Enplaning<br>Deplaning | • In case of emergency, bridges are generally being used as emergency exits.<br>• Since entering the apron or plane is normally forbidden, this might keep occupants from doing so in case of emergency. |
| Waiting areas | Waiting | • Pre-movement time is generally longer for those being seated. |
| VIP lounges | Waiting | • Pre-movement time is generally longer for those being seated. |
| Circulation areas | Moving | • Underground walkways can be more sensitive to fire and have less possibility for egress |


*Figure 9-3: Routes that are not accessible during normal operations, might neither be used during evacuation, because it creates a psychological threshold.*

The secondary processes, which are listed in table 8.2, might also cause delay of evacuation. Activities in amusement arcades and at public telephones are especially distractible to people in a way that leads them to pay less attention to the environment. They are trained to ignore the external signals and focus on a single activity, such as playing a game or having a conversation.

*Table 9-2: Secondary areas and processes within an airport terminal*

| Area | Process | Emergency topic |
|---|---|---|
| Restaurants | Ordering<br>Eating<br>Being seated | • Smoke might not be considered strange in restaurant areas.<br>• Pre-movement time is generally longer for those being seated. |
| Quick food and beverage services | Purchasing | • Pre-movement time is generally longer for those served. |
| Banks, ATMs, and money exchange desks | Changing money<br>Queuing | • People in long queues might not easily want to give up their position.<br>• Pre-movement time is generally longer for those served. |
| Tourist information | Obtaining information<br>Booking hotel | • People in long queues might not easily want to give up their position.<br>• Pre-movement time is generally longer for those served. |
| Shops | Purchasing | • Pre-movement time is generally longer for those served. |
| Barber shops | Getting a haircut | • Pre-movement time is generally longer for those being seated and served. |
| Shoe shine stands | Getting shoes polished | • Pre-movement time is generally longer for those being seated and served. |
| Car rental counters | Renting a car | • Pre-movement time is generally longer for those served. |
| Flight insurance company counters | Purchasing insurance | • Pre-movement time is generally longer for those served. |
| Public lockers | Locking luggage<br>Unlocking luggage | • Lockers are attractive places for placing bombs. |
| Public telephones | Phoning<br>Queuing | • While phoning, people pay less attention to the direct environment and are therefore less capable of adopting emergency signals.<br>• People in long queues might not easily want to give up their position. |
| Amusement arcades | Playing games | • While playing, people pay less attention to the direct environment and are therefore less capable of noticing emergency signals. |
| Public restrooms | Using the bathroom<br>Refreshing | • People tend to finish the activities performed in restrooms before evacuating. |

Another area with high risk is the restaurant area, as we saw in the list of recent airport emergencies. The equipment used in these areas is more likely to cause fire, and the bystanders in these areas are less alert to smoke, since it is normal that a certain amount of smoke comes from the kitchen.

Finally, a few notions concerning both the primary and the secondary processes. First, it is important to see that queuing people – especially those in long queues – are not eager to leave behind their position, because they have been standing there for a long time already. In airport terminals this might happen at the check-in desks, customs and security control, but it might also occur at ATMs and public telephones.

Second, the commitment of personnel to the activity they perform might be high. They carry responsibility and are not eager to leave behind their desk or shop. The closing of shops or the gathering of valuables might slow down the evacuation of personnel.

One should note that behaviour such as commitment cannot easily be recognised during emergency exercises. Nevertheless, it does have influence on the pre-movement time.

## 9.3 Terminal Layouts

The terminal layout depends on the nature of the air traffic to be handled at an airport. The design chosen is a function of factors, including the size and nature of traffic demand, the number of participating airlines, the traffic split between international, domestic, scheduled, and charter flights, the available physical site, the principal access modes, and the type of financing.[77]

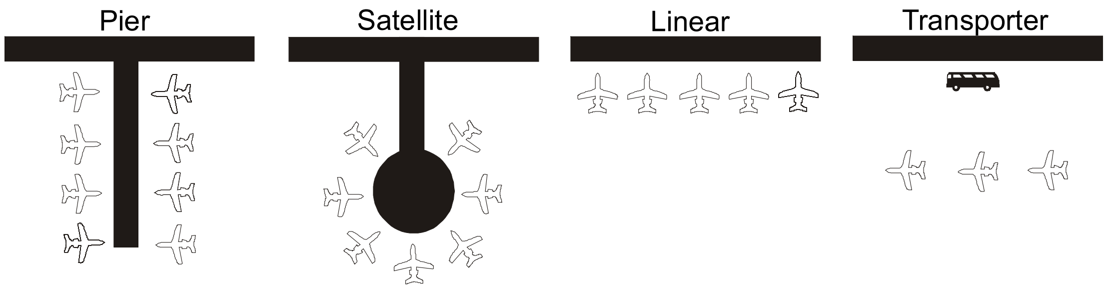


*Figure 9-4: Schematic drawings of the terminal concepts*

Different basic terminal designs with different area configurations can be distinguished, based on four different terminal and pier concepts (see Figure 9-4), each with its own advantages, and each appropriate to different situations[78-79]:

- Pier or finger
- Satellite
- Linear, frontal, or gate arrivals
- Transporter, open apron or mobile conveyance

[77] Ashford, N. and P.H. Wright (1992); Airport Engineering – third edition; p. 293
[78] Edwards, B. (1998); The Modern Terminal – New Approaches to Airport Architecture, p. 101
[79] Horonjeff, R. and F.X. McKelvey (1994); Planning & Design of Airports; fourth edition, pp. 466-476

Most airport terminals are combinations of the above fore layouts. Through time, airports have developed and demands and visions have changed. Beside this, some concepts are better suitable to one airline, while another concept is preferred by another. Combined concepts bear the advantages and disadvantages of the ideal layouts.

Beside this, there is also a difference in operational concept. The following two concepts can be distinguished:

- Centralised
- Decentralised

In the centralised terminal all elements in the passenger processing sequence, such as check-in, baggage checking, and customs and immigration, are performed in one area. Decentralisation involves a spreading of these functions over a number of centres in the terminal complex.

An interesting question is whether the terminal layout has any influence on the possible emergencies and the respective evacuations. It is likely that we can answer this question positively, since the density of people is different. Besides, some concepts imply the use of underground pedestrian routes, which might limit the possible escape routes.

In the following, a broader description of the mentioned layouts is given, with additionally their respective dangers, advantages and disadvantages during emergencies.

### Pier or finger

In this concept there is an interface with aircraft along piers extending from the main terminal area. The piers have a row of gates that give access to the aircraft parked on both sides. One of the major advantages is that there is an easy possibility to expand the piers, but it results in large walking distances between the terminal building and aircraft, which is a disadvantage.

The piers (or fingers) are structures with relatively low density of occupants, compared to terminals with central waiting lobbies, and provide easy access to the apron. Since occupants are generally not allowed to enter the airside of the airport, the problem in case of emergency might be that occupants tend to leave through the central exit, which would mean they move in the direction of the central terminal building. An advantage might be, that an evacuation of one pier might not cause disruptions to other piers.

### Satellite

The satellite concept consists of a central terminal with remote satellites that give access to the aircraft. The satellites can be reached by a surface, underground or aboveground connector. They can have common or separate departure lounges. Disadvantages are the relatively expensive connecting concourse infrastructure, long walking distances and lack of flexibility concerning the expansion of individual satellites.

A danger of this concept may be that satellites are often connected with underground pedestrian walkways, which might be more sensitive to fire and provided with few emergency exits. Smoke development will generally be higher in underground spaces.

If evacuation of the satellite is necessary, this means that there is a possibility that occupants will enter the apron. The conveyance back to the central terminal may cause disruptions. However, an advantage of decentralised terminals is that just a part of the airport is disrupted in case of an emergency in one of the remote satellites. Besides, fires might not jump over to other parts of the terminal as quickly as in connected buildings. There is a fair chance that the flights in other parts can continue, of course depending on the severity of the incident.

### Linear, frontal, or gate arrivals

The open apron or linear layout consists of a combined ticketing and waiting terminal, which exits leads directly to the parked aircraft. As a consequence, the walking distances within one terminal will be relatively short. This concept is flexible for expansion, though if the expansion consists of separate buildings, the use of common facilities is complicated.

In case of emergency evacuation all operations are disrupted, since the entire building is cleared. The advantage is the easy overview generated by the small scale of the facilities.

### Transporter, open apron or mobile conveyance

In this layout, the connection between the terminal building and the remote parked aircraft is provided by vehicular transport. The advantage of this concept is that it is relatively cheap, because of the minimal use of centrally used lounge space. However, the use of mobile lounges can increase the processing time of passengers and cause extra delays.

A danger of this layout is the high density of occupants within the terminal space. This might cause flow problems at bottlenecks in case of evacuation. In this case, exit widths might be more important than moving distances.

## *9.4 Airport Terminal and Emergencies*

The complexity of airport terminals, caused by the presence of different transport modalities, the massive addition of shops, restaurants, hotels and offices, creates a huge sensitivity. Through interactions between the different aspects, small incidents can easily lead to major disruptions. A small fire can lead to total evacuation, cancelled flights, delayed trains, et cetera.

In this paragraph we will have a closer look at the implications of the characteristics of the airport terminal building on emergencies. Therefore we will return to the following issues, most of which mentioned in chapter 6:

- Walkways, stairs and doors
- Emergency exits
- Lighting and emergency lighting
- Building layout and signage
- Emergency cues

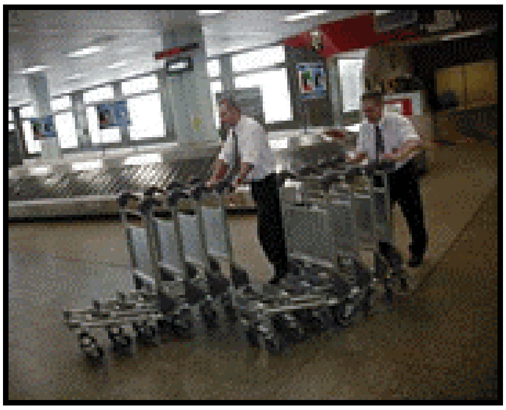 

*Figure 9-5: Luggage or luggage trolleys might be obstacles during evacuations, since they can block doorways.*[80]

## Walkways, stairs and doors

Airport terminals are generally very spacious buildings, with much room available for movement. There are few stairways or doors within the public zone of the airport, since they would cause obstructions to passengers with luggage. Therefore the movement through the building can be considered quite smooth. In some terminal buildings, the walking distances towards emergency exits might be more important than the limited capacity of the exits. Crushing can occur in areas where many people are concentrated and limited emergency egress is available. The crushing might even be stimulated by luggage or luggage trolleys, blocking the exits.

## Emergency exits

In airport terminals, some of the emergency exits will give access to areas that are generally prohibited, such as the apron. This might make people hesitate to use them. An example of an emergency exit from the bridge onto the apron can be seen in Figure 9-6.

Care has to be taken when power-actuated swinging and sliding doors are used, since they might not function during a power failure. During the Duesseldorf fire, a problem with these doors occurred because only one person possessed a master key to open the doors. They had to be forced open.[81]

## Lighting and emergency lighting

As in every building, lighting and emergency lighting is a big issue within airport terminals. It is hard to give general information on lighting in terminals, as the extent of lighting and daylight differs per terminal.

[80] picture taken from: www.newcastleairport.com
[81] Wolf, A. (1996); Seventeen Die in Duesseldorf Airport Terminal Fire; NFPA Journal July/August

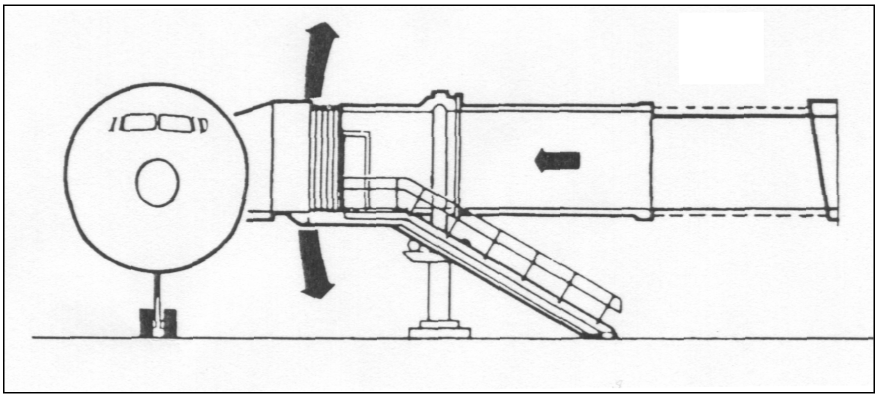

*Figure 9-6: Bridges are frequently used as emergency exits. Disadvantage is that the evacuees enter the apron.*[82]

## Building layout and signage

Signage is an important aspect within terminals, because the majority of the people are not very familiar with the building. Emergency egress routes should be well indicated. The problem is, though, that not only the emergency routes need indications, but also the normal processes. Therefore, terminal buildings are generally full of signs, varying from signs with texts to pictograms. In case of emergency, this might cause 'competition' between the normal signs and the emergency signs, resulting in a situation in which people oversee the egress signage.

Signage itself might not prevent people from noticing a useful facility. For example, during the Burger King fire at Amsterdam Airport Schiphol, the occupants being evacuated did not notice, and therefore not use, the emergency facility in a revolving door. The evacuation was delayed until an employee opened the sliding doors within the revolving door. [83]

## Emergency cues

The cues people receive during an emergency determine their initial behaviour and the pre-movement time. Within most airport terminals, a good public address system is available. The address system at Amsterdam Airport Schiphol can broadcast local messages and global messages. In general, these messages are provided in two languages, English and Dutch. The voice annunciation system in Duesseldorf even provided instructions in German, English, and French at the time of the terminal fire.

The availability of public address system, of course, does not mean that it can always be used, or that it is always used properly. During the Burger King fire at Schiphol Airport for example, the public address system could not be used due to the evacuation of the responsible personnel. The information had to be provided by other personnel and the Royal Army Police. In Duesseldorf the system played the wrong tape for about 10 minutes. [84-85]

Initial cues, though, are generally not provided by the public address system, but by the emergency itself. The problem is, as noticed before, that people tend to neglect these

[82] picture taken from: IATA (1995); Airport Development Reference Manual; 8th edition
[83] Bakker, N.; Amsterdam Airport Schiphol, Safety Manager; interview on June 8th 2001
[84] Bakker, N., Amsterdam Airport Schiphol, Safety Manager, interview on June 8th 2001
[85] Wolf, A. (1996); Seventeen Die in Düsseldorf Airport Terminal Fire; NFPA Journal July/August

cues. For example: during the trial on the Duesseldorf airport fire some witnesses declared that initially none of the occupants really cared about the fire. No one used a fire extinguisher and the normal processes continued. Some occupants considered sparkles coming from the ceiling to be fireworks to welcome someone.[86]

[86] Friedrichsen, G. (2001); ,,Dieser Fall ist nicht Vorgesehen''; in: Der Spiegel 24, 2001

# 10 Airport Terminals: Occupants and Behaviour

In this chapter concepts for exploring ways of simulating the behaviour of occupants of airport terminals in case of emergency will be explored. First an actor model will be presented, containing all the people that might be present in airport terminals and their activities. Then, Canter's behaviour model will be revised to take into account the special characteristics of airport occupants and airport terminal buildings.

## 10.1 Occupants in Airport Terminals

Within airport terminals many different occupants can be distinguished. Wenzel[87] sees two different categories of terminal users: the actors offering services, such as airline personnel and shopkeepers, and those using these services, such as passengers.

As seen in the previous paragraphs, people generally tend to act according to their personal characteristics, like role and responsibility. In this paragraph the occupants within airport terminals and their respective characteristics, roles and responsibilities are represented in an actor model.

Sime[88] states, that if one is trying to predict the evacuation time from a setting such as an airport passenger terminal it is crucially important to examine the nature of behaviour in normal circumstances and therefore during the early stages of an emergency when most time is lost. Therefore, on the one hand attention is given to the activities of the different actors during non-emergency situations and their commitment to these activities, and on the other hand to the roles and responsibilities during emergencies.

The information below concerning airport police, security personnel, customs and the in-house emergency and first-aid service describes the situation at Amsterdam Airport Schiphol. Of course, other airports will utilise different organisational concepts. The information here is meant as an example.

### Airline passengers

The largest category of airport occupants is airline passengers. Airline passengers are defined as the occupants that depart from and/or arrive at the airport by aeroplane. They could be subdivided according to different characteristics:

- leisure or business travellers
- charter or scheduled flight passengers
- long distance or short distance flight passengers
- frequent flyers or non-frequent flyers
- originating passengers, terminating passengers or transfer passengers

Leisure travellers or tourists usually spend a lot of time at the airport. They arrive early in order not to miss their flight and use the time after check in to do tax-free shopping or to

[87] Wenzel, Dr.-Ing. P. (1999); Fußgänger-Leitsysteme – Planung von Leitsystemen in Fußgänger-Verkehrsanlagen am Beispiel von Fluggast-Empfangsgebäuden; p.21
[88] Sime, J.D. (1995); Crowd Psychology and Engineering; in: Safety Science 21, pp. 1-14

have a refreshment in a restaurant area. Business travellers spend less time and money in areas of non-deductible business expenses; however, restaurant areas and bars are full of these travellers. In general, tourists carry more pieces of luggage than business travellers and travel more often in groups. At some airports, business travellers with only hand luggage are able to check in by means of computer terminals. Beside this, having no luggage these passengers do not spend time in the reclaim area at the airport of arrival. Business travellers are seldom accompanied to or from the airport by meeters and greeters.

Differences in behaviour are also linked to whether one has booked a charter flight or a scheduled flight. Charter flights are generally occupied by leisure travellers, and often encounter difficulties like long processing times at passenger and baggage check-in, and the non-availability of alternate flights if the booked flight is missed.

It is generally acknowledged that intercontinental or long-distance passengers arrive earlier than those who have booked a short-distance flight. Therefore they will spend more time in the terminal building.

Frequent flyers and non-frequent flyers can be distinguished by their knowledge and experience concerning the procedures within and the layout of the terminal. Frequent flyers, most of them business travellers, generally need less time to find their way within the terminal.

The originating passengers are passengers that arrive at the airport by car, train or bus, and depart from the airport by aeroplane. Terminating passengers arrive by plane and leave using other means of transport. They move both through the public parts of the airport and the secured zone behind the security control. Originating passengers have to check in, pass the security and walk towards their gate. Destination passengers move from their gate towards the reclaim area in order to collect their luggage before going through the passport check. Transfer passengers arrive and depart by aeroplane, while at the airport they remain in the security zone. Transfer passengers do not carry heavy luggage, since this is automatically transferred from their incoming flight towards their outgoing flight. They already possess their boarding card and just move from the gate of arrival to the gate of departure. [89]

During emergencies passengers might have specific roles and responsibilities. These can vary from being a father to save his family to being a doctor having occupational responsibilities. Generally, though, the passengers have only one responsibility, which is to evacuate themselves. Problems during evacuation can be caused by heavy luggage, disabilities, and commitment to their current activity, such as having a meal in a restaurant or lining up for check in.

### Escorts, meeters and visitors

Escorts are the persons that escort the airline passenger to the airport. Meeters are the persons that collect the arriving passengers to take them home. In most countries, both escorts and meeters cannot enter the security zone. In the United States they can accompany travellers to the gate. Escorts and meeters generally do not carry heavy luggage. Due to flight delays, meeters might stay for a long time in the public zone of the terminal. Escorts generally do not stay for a long time.

An airport with its aeroplanes is an interesting attraction to many people. A part of the population within the terminal will be visitors, who come to have a look at the airport,

[89] Ashford, N. and P.H. Wright (1992); Airport Engineering – third edition; p. 299

without having the objective to travel by plane. In most countries apart from the US, they will be only found in the public zone of the airport, especially at locations where a view on the airside of the airport is provided.

The roles and responsibilities of escorts, meeters and visitors during emergencies are similar to those of airline passengers.

### Airport police, security personnel, and customs

The airport police are responsible for security at the airport. Security personnel are hired by the airport police to control the security lanes. At Schiphol the airport police (Koninklijke Marechaussee – Royal Army Police) have the additional task of passport control. Beside this, they provide people with visas, try to prevent illegal persons from entering the country, and try to trace illegal activities within the terminal.

The customs workers at Schiphol Airport are responsible for seeing that no illegal goods are smuggled into or out of the country. At Schiphol they are positioned at the exits of the reclaim area and at the connections between EU and non-EU parts of the terminal.[90]

The airport police, security personnel and customs are trained to deal with uncommon situations, including emergencies. They are supposed to be informed early and know the layout of the terminal and certain standard actions and procedures to perform. The police are responsible for taking care of the safety of the people. Their role during evacuation will be to direct occupants safely out of the building and to control the emergency.

One of the advantages of having police, security personnel and customs workers on the scene during emergencies is that they wear uniforms, which gives them a certain authority. People tend to listen better to people in authority, which is emphasised by their uniform, than to 'laymen'. This is for example shown during the fire in King's Cross Underground station in London in 1987. According to Donald and Canter[91]:

> *,,The crucial role of the police appears to stem from both their general experience and training, and from people's reactions to them as figures of authority. While the public are capable of playing a role in directing and informing other members of the public, it seems likely that they will be ignored. (...) The reactions of the public to underground staff appears to have been similar to their response to fellow travellers."*

### Fire officers

In the case of airports we can distinguish two different fire departments with their respective firemen. On the one hand there is an airport fire department located at the airport itself, responsible for fires at the airside of the airport. On the other hand there is a municipal fire department, often not situated at the airport.

In the case of Schiphol, co-operation between the airport fire service and the local fire brigade is arranged by means of a mutual agreement between the airport and the municipality of Haarlemmermeer. This agreement gives the airport fire service overall

[90] Visser, R.J. (2000); Sturen zonder Handen, Ontwikkeling van een Besturingsmodel voor de Centrale Security op Schiphol; final thesis Delft University of Technology, pp. 11-21
[91] Donald, Ian and David Canter (1990); Behavioural Aspects of the King's Cross Disaster; in: D. Canter (editor, 1990), Fires and Human Behaviour; second edition, pp. 15-30

control of fire fighting and rescue in case of an aircraft accident on the airport, while the airport fire service acts as a substation of the local fire brigade during other incidents on the airport, like a fire in the passenger terminal. Because of the close location of the airport fire service they will be the first active unit when fire is reported.[92]

In case of fire, the fire departments will be alerted. Their tasks will be to fight the fire and to secure the safety of the occupants of the building. They can direct occupants out of the building or inform other emergency resources to do so. They are well-trained for the circumstances and beside this fully equipped, so they have better possibilities to move through smoke and fire, both psychologically and physically.

Like the airport police, the security personnel and the customs workers, the firemen have the advantage they have authority due to their uniforms and expected experience.

### Airline personnel

The airline personnel can be subdivided into flight-related personnel and ground personnel. The flight-related personnel are the pilots, stewards and stewardesses, while the ground personnel work in the terminal, for example at the check-in desks. When in the terminal, airline personnel generally work within the security zone, e.g. where passengers get their boarding passes checked by airline personnel, but at the end or the start of their shifts they can be found in the public zone of the airport terminal.

Airline personnel have knowledge about airports in general, and often also about the specific airport where they are at the moment. The flight-related personnel are trained in emergency procedures in the aeroplane. Although they usually do not have responsibilities within the terminal, this training and education might influence the way they act during emergencies in the terminal, because they feel responsible for the passengers. The effect of airline personnel uniforms on the pubic is unknown.

### Retail area personnel

Most of the personnel of the shops and restaurants within the terminal building, summarised with the term ‘retail area personnel’, have good knowledge of the terminals, since they work there almost every day. The activities they perform in normal situations consist of selling goods or waiting or cooking in restaurants.

The shops and restaurants at Schiphol Airport carry their own responsibilities concerning safety on their premises. Some of the personnel might have a special role as emergency assistant within the entire terminal building. Usually, though, they are not trained for emergency purposes. Retail personnel also have responsibility for the money and goods within their shop and therefore a commitment to their activity. This might cause a delay in their own evacuation, for example when they want to close the shop safely before leaving.

### In-house emergency and first-aid service

Airports generally have in-house emergency and first-aid services at their disposal. Amsterdam Airport Schiphol for example is obliged by law to be provided with in-house emergency assistants[93]. These so called ‘Bedrijfshulpverleners’ or BHV-ers are normal

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[92] Turnbull, Aidan; Amsterdam Airport Schiphol: Fire-fighting and Rescue; at: http://www.airportfire.com
[93] Bakker, N., I. Tiessens, C. de Vries (2001); BHV-plan voor mobiele en lokale Bedrijfshulpverleners; Schiphol Group

employees of the airport itself or institutions operating at the airport, trained to provide first aid, to relax the victims and the bystanders, to extinguish a small fire, to inform and guide the professional emergency resources towards the emergency or victims, to alarm occupants and evacuate the building, and to give feedback to their superiors.

At Schiphol approximately 550 emergency assistants are active, divided in time and space. Each part of the terminal, such as piers, lounges and reclaim area, has its own local emergency-team, consisting of a number of emergency assistants. In case of emergency, this local team will be supported by a mobile emergency team. Schiphol has defined a time limit, prescribing that the emergency team should be at the location of the emergency within three minutes after the alarm.

In-house emergency and first-aid service personnel can play an important role in the evacuation of people from the airport building. If they are able to guide people to the nearest emergency exit, long walking distances can be avoided. At Schiphol, emergency assistants have access to emergency closets containing tools, electric torches, helmets, megaphones, a fire extinguisher, a first aid kit, et cetera. These objects can simplify one's own escape or the organisation of the evacuation of others. Emergency assistants wear orange or yellow fluorescent vests and are easily recognisable.

### Other airport personnel

Many more people than the ones mentioned above work within an airport terminal, for instance the people at information desks, the reclaim area personnel, the IHD (International Help to Disabled) assistants, cleaners et cetera. It is too much to describe them all individually here. However, most of them are merely individuals to be evacuated and do not play a special role in the evacuation process.

### Criminals and homeless people

Airport terminals are like cities, and have to deal with many urban problems. Inattentive tourists with money, valuables and luggage attract pickpockets, the warmth of the terminal building attracts homeless people. The number of airport inhabitants should not be underestimated. According to the Volkskrant[94] for example, 20 criminals and 200 homeless people 'work and live' in the public area of Amsterdam Airport Schiphol. In January 2001 at this airport a homeless person set fire in a public toilet, causing an explosion[95]. The occupants had to be evacuated and the terminal was closed for approximately four hours[96]. In the United States these persons can also enter the security zone, since no boarding pass is to be shown at the security control.

During emergencies they might have different objectives than to escape directly, as they are interested in the belongings of others instead of their own safety. Beside this, the homeless people might show a slower reaction because of the use of alcoholic beverages.

[94] Volkskrant (2001); Schipholdief lacht om 'veiligheidsgassies'; June 19th, 2001
[95] Trouw (2001); Weer brand op Schiphol; April 10th, 2001
[96] Schiphol Group (2001); Operations at Schiphol Airport Almost back to Normal; Press release January 18th, 2001; at: www.schiphol.nl

## 10.2 Emergency Behaviour in Airport Terminals

After having identified the airport terminal's occupants and characteristics, we will have to define what subsequent behaviour we can expect.

### Canter's model applied

In order to determine how to simulate the emergency behaviour of persons in terminal buildings, we will adapt Canter's behavioural model, which was presented in chapter 7, and apply it to terminal occupants. The adapted model is shown in Figure 10-1.

The pre-fire activity consists of one of the activities performed within airport terminals, such as buying tickets, checking in, waiting for departure, et cetera, such as listed in chapter 9.2 .

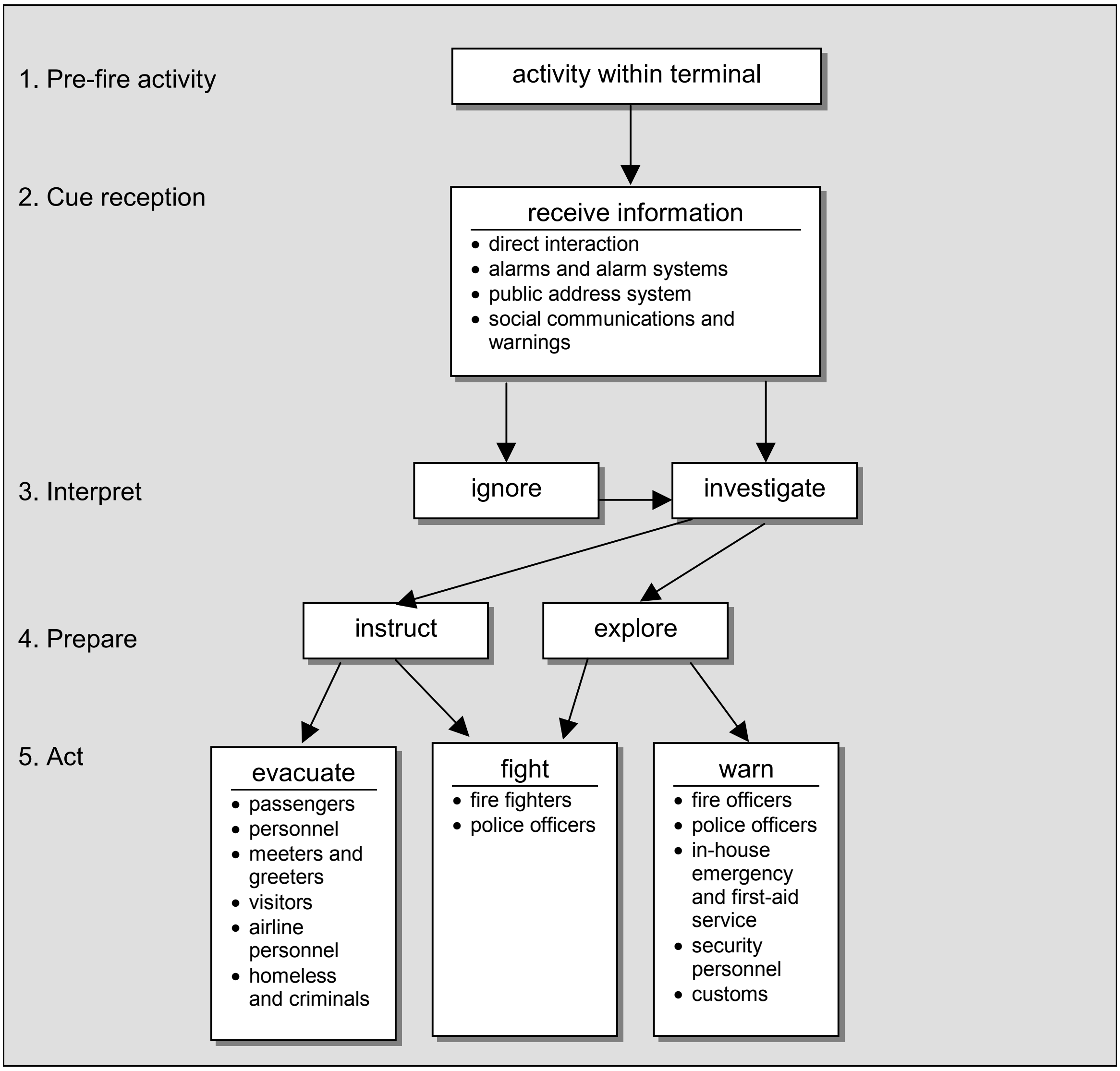



*Figure 10-1: Canter's model of human behaviour in fire, adapted to airport terminal emergencies. The possibilities to withdraw and to wait are eliminated.*

The cue reception phase in airport terminals is characterised by direct interaction of the occupants and the emergency, alarms and alarm systems, public address systems with spoken messages, or by social communications between people that warn each other.

In his studies concerning human behaviour in fires, Canter concludes that the frequency of fire fighting is closely associated with the type of building, accounting for almost one-quarter of the first actions taken in factories compared to only one-tenth in dwellings. As only a very small percentage of airport occupants will be at the exact location of the emergency, close enough to try to avoid growth, and feel himself responsible to do so, the emergency fighting action is just performed by the emergency resources fire department (in case of fire) and police. In-house emergency and first-aid service people, security personnel and customs might assist these resources in warning people, while the others evacuate.

The ‘withdrawal’ and ‘wait’ blocks are entirely eliminated from the model, since withdrawal as preparation before waiting to be instructed or evacuated mainly takes place in hotels, where the privacy and self-reliance associated with being a hotel guest seems crucial. People return to their rooms and wait for further instructions. It is assumed that no occupants in terminals will show withdraw behaviour and that occupants not belonging to the emergency resources, as soon as they are aware of the emergency, will try to leave the building.

The acts of terminal occupants will consist of evacuating, fighting the emergency or warning others, according to the occupant’s role. Most of the normal occupants, such as passengers, personnel, meeters and greeters, et cetera, will leave the building as soon as they notice an emergency, although some of them might try to help the emergency services with warning others and fighting the emergency. Fire officers and police officers will generally be in charge of the fighting: fire officers in case of fires and explosions and gas leaks et cetera, and the police during emergencies like bomb threats and terrorism. Together with other actors like the in-house emergency and first aid service, the security personnel and the customs, the police and fire officers warn the terminal occupants.

## Relevant human characteristics

In this paragraph we aim to list which individual characteristics are of importance in airport buildings during emergencies. The important characteristics should be included in the simulation model.

- **Gender and age**
  For the escape behaviour of people in airport terminals the gender and age are important, but not more important than in other settings.
- **Physical disabilities**
  Physical disabilities could be more important in airport terminals, especially when we consider people with luggage or luggage carts as physically disabled too. Airport terminals generally have long walking distances, which means that even the routes towards the emergency exits could be long, especially if we consider the fact that people tend to return to an entrance they previously used. During an emergency, people can get injured as well, for example due to contact with fire. Therefore, this individual characteristic can be considered dynamic during the emergency.
- **Psychological disabilities, personality, mood**
  For the escape behaviour in airport terminals, psychological disabilities, personality, and mood are not more important than in most other settings, with the exception of mental institutions and hospitals.
- **Training, experience and education**

Airport and airline staff, including the in-house emergency service can be considered trained and educated, and therefore play an important role in informing and guiding the people that are unfamiliar with the building and with emergency situations. The customer-staff ratio is of great importance

- **Language skills**
  Language skills are extremely important within terminals. Within buildings like airport terminals the occupants have their origin in different parts of the world. Many of them will be able to understand at least some English, but not all of them. These people have to be instructed too, and will be dependent on other cues.
- **Alertness and state of consciousness**
  Concerning alertness and state of consciousness within terminal buildings, we can assume that people are generally awake and sober, though the intercontinental passengers might be less alert due to long flights and jet lags. The homeless people might be an exception.
- **Independence and dependence**
  The number of dependent occupants in airport terminal buildings can be considered low, compared to for example hospitals and prisons. Some disabled people are in need of help, as well as under-aged children.
- **Roles, rules and responsibility**
  An airline passenger behaves according to certain roles, rules and responsibilities. He probably does not feel responsible to fight the emergency, but on the other hand he will feel responsible for his family, in which he has a certain role. The rules within airport terminals are quite strict, for example concerning the boarder and security. Passengers usually accept these rules, and might not tend to neglect these rules in case of emergency.
- **Affiliation**
  Passengers carry along luggage and are often together with family members or friends. They might not easily leave them alone, which has impact on escape behaviour. On the other hand, the large amount of business passengers and staff could mean that many people are not that much attached to belongings or others.
- **Current position**
  As in other settings, the current position of an occupant in airport terminals is crucial, since it determines the amount of danger and the possibilities to escape.
- **Commitment to activity**
  Some activities within terminals have larger commitment than others, like waiting for luggage in the reclaim area and queuing before the check-in.
- **Focal point**
  Within airport terminals there is no relevant focal point, which might cause people to have higher response times.

## Group behaviour

Airports house large amounts of people. The social influences must therefore not be underestimated. In many cases the individual decision making might be based on the behaviour of others around the individual. This might be passenger-passenger interaction, passenger-staff interaction, and staff-staff interaction.

The most important characteristic of airport terminals is the large amount of staff present, which might cause different evacuation scenarios than with less staff, since people can be more easily guided.

# 11 Conclusions Theory Applied to Airport Terminals

In this chapter we will summarise the most important conclusions of this literature research point by point. How we used these conclusions during the implementation phase, will be described in the next chapters. A schematic overview of the translation steps can be found in Appendix II.

## 11.1 Airport Terminals: Building Characteristics

- The behaviour performed in case of emergency depends highly the physical location and properties of the area, and on the current activity performed within the area.
- Especially the waiting queues generated at some locations might cause increased pre-movement times. It is important to see that queuing people are not eager to leave behind their position, because they have been standing there for a long time already.
- During an emergency, areas that are generally not accessible, such as the apron, or only accessible after a certain procedure, such as a passport check, might be a barrier to some occupants, which causes the time to escape to increase.
- Activities in amusement arcades and at public telephones are especially distractible to people in a way that leads them to pay less attention to the environment.
- Another area with high risk is the restaurant area, since the equipment used in these areas is more likely to cause fire, and the bystanders in these areas are less alert to smoke.
- In the retail area, the commitment of personnel to the activity they perform might be high. The closing of shops or the gathering of valuables might slow down the evacuation of personnel.
- Terminal layout has an influence on the possible emergencies and the respective evacuations. The presence of underground pedestrian routes and the density of people are important factors.

## 11.2 Airport terminals during emergencies

- Care has to be taken when power-actuated swinging and sliding doors, or elevators are used, since they might not function during a power failure.
- Crushing can occur in areas where many people are concentrated and limited emergency egress is available. The crushing might even be stimulated by luggage or luggage trolleys, blocking the exits.
- Terminal buildings are generally full of signs, varying from signs with texts to pictograms. In case of emergency, this might cause ‘competition’ between the normal signs and the emergency signs, resulting in a situation in which people oversee the egress signage.
- Within most airport terminals, a good public address system is available. The availability of public address system, though, does not mean that it can always be used, or that it is always used properly.
- Initial cues are generally not provided by the public address system, but by the emergency itself. In large buildings such as terminals, these cues are available to a small part of the population. The problem is that people tend to neglect these cues.

## 11.3 Airport terminals: occupants and behaviour

- Within airport terminals many different occupants can be distinguished. We can see two different categories of terminal users: the actors offering services, such as airline personnel and shopkeepers, and those using these services, such as passengers.
- It is crucially important to examine the nature of behaviour in normal circumstances and therefore during the early stages of an emergency when most time is lost.
- Airline passengers can be subdivided according to different characteristics, such as leisure or business travellers, charter or scheduled flight passengers, et cetera. The different categories show different behaviour within the terminal.
- Problems during evacuation can be caused by heavy luggage, disabilities, and commitment to their current activity, such as having a meal in a restaurant or lining up for check in.
- The airport police, security personnel and customs are trained to deal with uncommon situations, including emergencies. Their role during evacuation will be to direct occupants safely out of the building and to control the emergency.
- In case of fire, the fire departments will be alerted. Their tasks will be to fight the fire and to secure the safety of the occupants of the building. They can direct occupants out of the building or inform other emergency resources to do so.
- Although airline personnel  usually do not have responsibilities within the terminal, training and education might influence the way they act during emergencies in the terminal.
- If in-house emergency and first-aid service personnel are able to guide people to the nearest emergency exit, long walking distances can be avoided.
- During emergencies, criminals and homeless people be interested in the belongings of others instead of their own safety. Homeless people might show a slower reaction because of the use of alcoholic beverages.

## 11.4 Emergency behaviour in airport terminals

- The pre-fire activity consists of one of the activities performed within airport terminals, such as buying tickets, checking in, waiting for departure, et cetera.
- The cue reception phase in airport terminals is characterised by direct interaction of the occupants and the emergency, alarms and alarm systems, public address systems with spoken messages, or by social communications between people that warn each other.
- As only a very small percentage of airport occupants will be at the exact location of the emergency, close enough to try to avoid growth, and feel himself responsible to do so, passengers are presumed not to perform fire fighting activities.
- The emergency fighting action is just performed by the emergency resources fire department  and police. In-house emergency and first-aid service people, security personnel and customs might assist these resources in warning people, while the others evacuate.
- Most of the normal occupants, such as passengers, personnel, meeters and greeters, et cetera, will leave the building as soon as they notice an emergency.
- Specifically within airport terminals, individual characteristics such as physical disabilities, number of luggage pieces, training, experience and education, language skills, affiliation, commitment to activity, are of importance.

- Social influences and group behaviour within airport terminals must not be underestimated.
- A very important characteristic of airport terminals is the large amount of staff present, which might cause different evacuation scenarios than with less staff, since people can be more easily guided.

# PART IV

# Building the Evacuation Model

# 12 Implementation: new building blocks

In this chapter, the implementation phase will be described. Based upon the knowledge gathered until now, new building blocks for the existing Airport Passenger Library have been constructed, and existing objects have been changed in order to be able to simulate situations of evacuation.

First, we will give a qualitative description of escape behaviour, related to the Airport Passenger Library. Then, the new objects created in order to be able to simulate an evacuation, the order of events, and the interaction between the new objects are described. At the end of this chapter, we will discuss the simplifications that have been made, and the assumptions on which this structure was based.

## 12.1 *Evacuation behaviour modelling*

Groups are supposed to escape according to certain behavioural rules. This behaviour can be seen as a result of the interaction between certain attributes. We can distinguish three types of relevant attributes:

- **Personal attributes**
  Personal attributes are attributes related to a group or an individual occupant within the airport terminal, e.g. age, gender, familiarity with the building, or number of luggage pieces.

- **Local attributes**
  Local attributes are connected to the areas, e.g. area capacity, surface, number of seats, occupant density, number of exits, affection by the emergency.

- **Global attributes**
  Global attributes relate to the entire system, and they are the same for each group and each area. This can for example be the quality of the signage through the entire building, the number of cues given through the public address system, or the number of emergency resources generally available.

Some attributes can be both local and global, such as signage. The signage could be specified on a high level of abstraction (the entire building), or at a lower level of abstraction (a single room).


*Figure 12-1: Behaviour during emergency depends on personal, local and global attributes.*


*Figure 12-2: The pre-movement time and route choice of groups will be based upon local and global attributes. Personal attributes have not been taken into account yet.*

The interaction between these parameters leads to certain behaviour, according to rules. Some behaviour can as well be influenced by stochastic distributions. A graphical representation is shown in Figure 12-1.

In this model, we have chosen to design a rule set that consists of a pre-movement time and an escape direction. This means that at the moment an emergency breaks out a group gets assigned those two parameters, depending on the area in which a group is situated at the moment an emergency starts. This can be seen in Figure 12-2.

The assignment of these parameters in this model will not depend on the personal attributes. The area randomly determines an occupant's behaviour, not taking into account its individual characteristics, such as age, gender and alertness. There are a few reasons for this. Firstly, the relevant characteristics have influence on three main characteristics: the walking speed, the pre-movement time and the route choice. In the appendices Appendix VIII, Appendix IX and Appendix X this is clarified by means of three diagrams. Varying these three parameters already gives a lot of possible scenarios.

Secondly, it would be very time consuming, if not impossible, to find out the exact properties of the population for each flight schedule used. Besides, it is questioned if this increased level of detail will lead to more valuable results, since we work with very large populations. Therefore, in this simulation, the population is not very specifically determined in terms of individual characteristics. In future, though, the model could be easily extended, making script and pre-movement time assignment depend on the personal attributes of the groups as well.

## 12.2 New objects

In this paragraph, the recently created emergency and evacuation objects will be introduced. A more schematic overview of the objects can be found in the object model in Appendix II.

It is important to see that there is a clear distinction between the global level and the local level. At a global level, we have created two control objects:

- Emergency Control object
- Evacuation Control object

Both objects have to be placed within the Mission Control frame of the model. In these two building blocks, general input valid for respectively the entire emergency and the entire evacuation can be entered.

Beside this, these objects both have local equivalents, situated in each area object:

- Area Emergency Control object
- Area Evacuation Control object

Within these objects, the area specific information is processed. By doing so, we will not have to store unnecessary information centrally.

Next to these control objects, we have created the following other objects:

- Emergency Exit object
- Emergency Scripts
- Script statement “SetDestClosestExit”
- Evacuation Statistics object

For reasons of clarity, only the new objects within the Airport Passenger Library will be presented here. A list of the objects, adapted or changed during this research, is presented in Appendix IV.

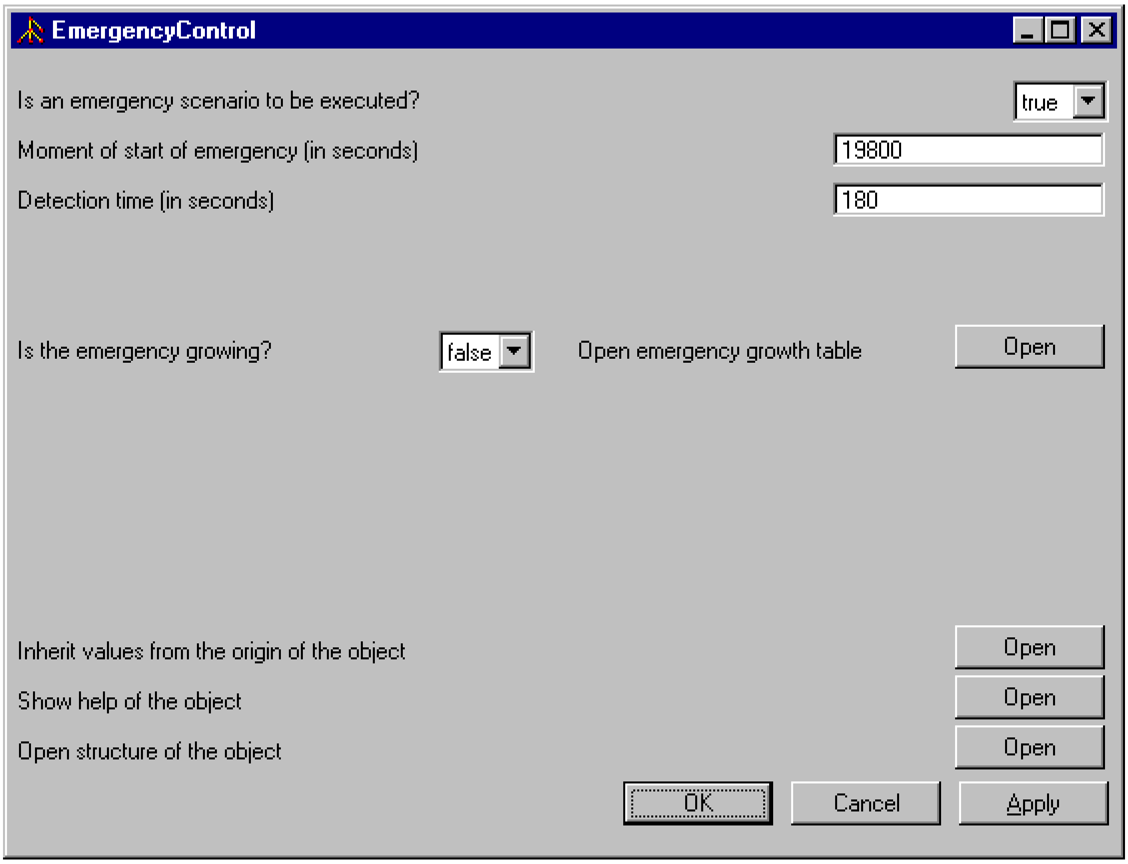


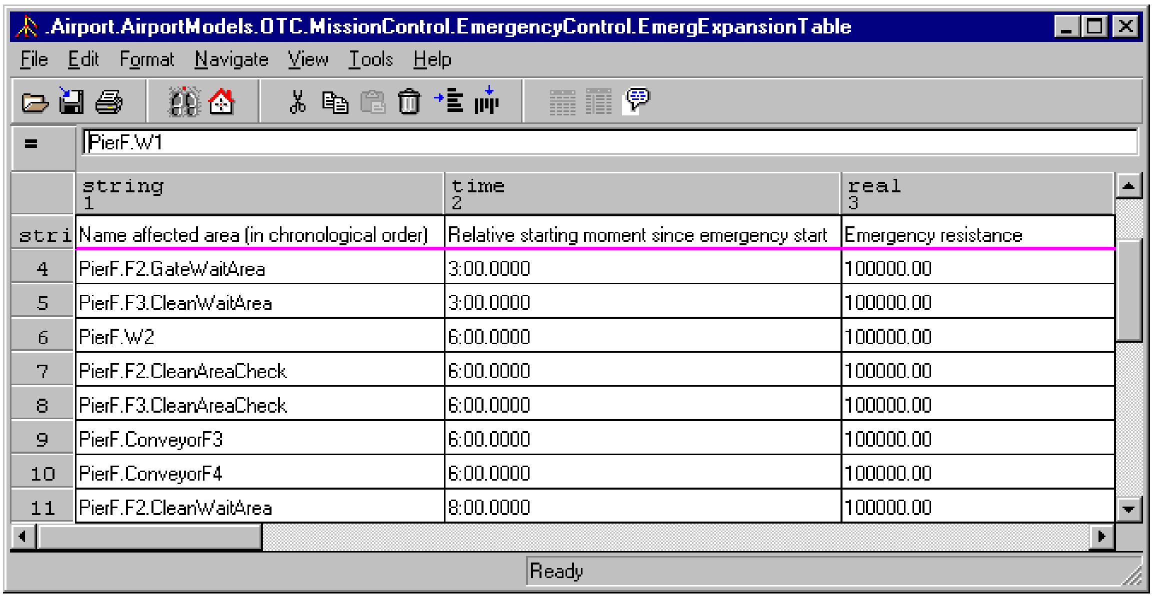

*Figure 12-3: The user input of the Emergency Control.*

## Emergency Control Object

The central Emergency Control object controls start, growth and consequences of an emergency. It informs areas about the fact they are affected by an emergency, and increases the resistance of the area, so it will not be taken into account by the shortest path algorithm. Furthermore, it triggers the Evacuation Control.

In Figure 12-3 we can see the dialog with user input, which we will obtain when we double click on the object. In the first line, we can choose whether we want to execute an emergency scenario or not. This way we can also simulate normal operations, without having to delete the Emergency Control object. In the next lines the user is able to specify the moment the emergency starts, and the detection time, after which the evacuation will start.

Furthermore can be decided whether the emergency is growing, and if so, how it will grow through the building. The Emergency Growth table (Figure 12-4) contains the details of the growth scenario, listing the areas to be affected and the moment on which the emergency reaches this very area. The input of this table can either be user-defined, or come from an external fire growth software tool.




| | string 1 | time 2 | real 3 |
|---|---|---|---|
| stri | Name affected area (in chronological order) | Relative starting moment since emergency start | Emergency resistance |
| 4 | PierF.F2.GateWaitArea | 3:00.0000 | 100000.00 |
| 5 | PierF.F3.CleanWaitArea | 3:00.0000 | 100000.00 |
| 6 | PierF.W2 | 6:00.0000 | 100000.00 |
| 7 | PierF.F2.CleanAreaCheck | 6:00.0000 | 100000.00 |
| 8 | PierF.F3.CleanAreaCheck | 6:00.0000 | 100000.00 |
| 9 | PierF.ConveyorF3 | 6:00.0000 | 100000.00 |
| 10 | PierF.ConveyorF4 | 6:00.0000 | 100000.00 |
| 11 | PierF.F2.CleanWaitArea | 8:00.0000 | 100000.00 |

*Figure 12-4: Example of an Emergency Growth table.*

## Evacuation Control Object

During emergencies, the Evacuation Control object controls the movement of occupants through the building. This object calls the Area Evacuation Control block in all areas to evacuate their groups. The user can choose within this object whether he wants pre-movement time and evacuation scripts to be assigned locally or globally.

If global assignment is chosen, one pre-movement time distribution and one script assignment table are used for the entire model. This global parameter will be stored in the central Evacuation Control object. In case of local assignment, pre-movement time and evacuation script are area specific, and therefore stored in the different Area Evacuation Control objects. The latter, of course, is the more sophisticated option, since this will offer the possibility to take local characteristics into account, such as the visibility of the exits, the signage within the area, et cetera. Beside this, the commitment to an activity could play a role of significance, addressing a larger pre-movement time to for example people in queues or restaurants.

The dialog frame in Figure 12-5 shows the user input for this object. Similar to the Emergency Control, we can choose whether an evacuation is to be executed or not. If so, we can choose between global or local pre-movement time and script assignment. For local pre-movement time assignment we need the area table, containing all areas in the model, and the user-assigned area-specific pre-movement times. In case of global script assignment it will be necessary to fill out the script assign table, containing the possible scripts and the chance that a group is assigned this script.

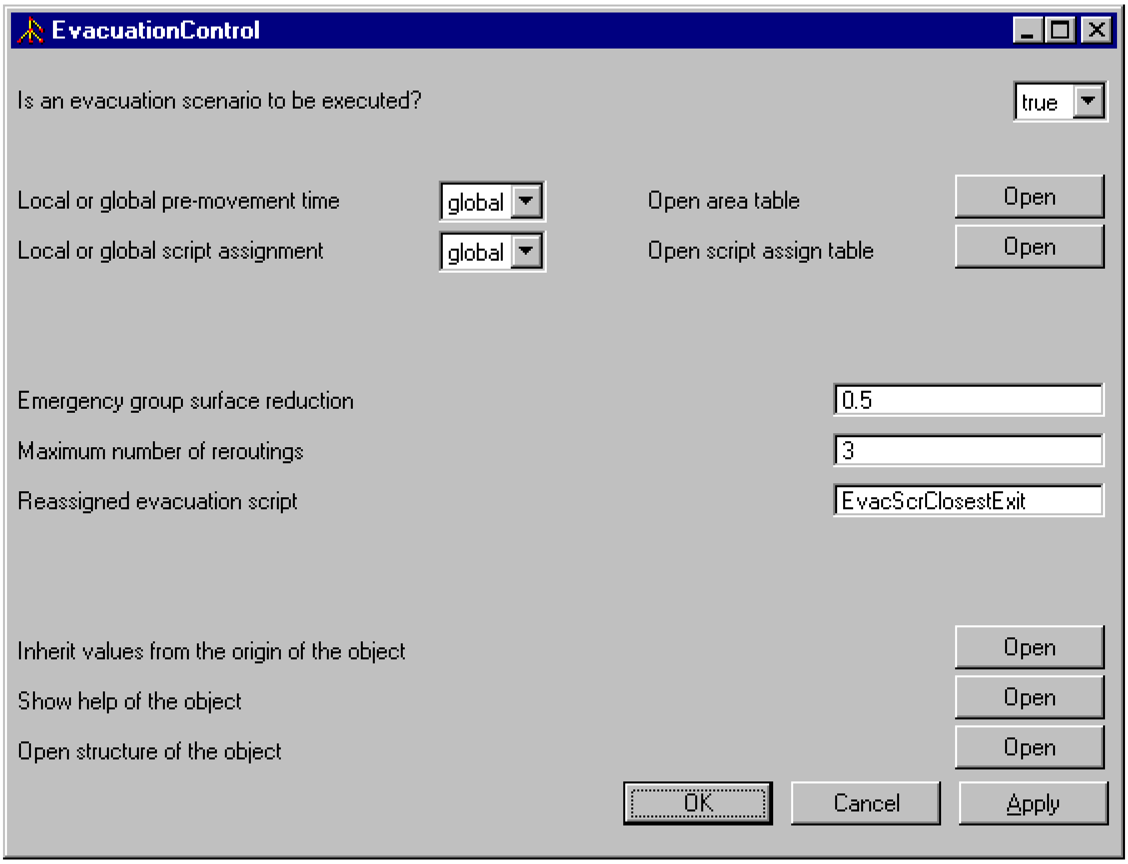



*Figure 12-5: The user input of the Evacuation Control*

The next parameter, called “Emergency group surface reduction”, describes the surface reduction of a group after the emergency broke out. This describes the concept of more people fitting onto a smaller surface in case of emergency. When people escape, they accept to use less space than in normal situations, when they wish to keep people at a certain distance. A surface reduction of 0.5, for example, describes a situation in which a person that normally needs two square metres to feel comfortable, only needs one square metre during emergencies.

The maximum number of re-routings refers to the number of times a group is reassigned an evacuation script. In case a group requests to enter an area that has been blocked because it is affected by the emergency, it will receive a new destination. It could happen, that groups get trapped, and keep running from one closed escape route to the other, without getting out. The maximum number of re-routings determines how many times a group can get re-routed before it is considered to be trapped. Trapped groups will be removed from the model, and registered.

The re-assigned evacuation script is the script that a group will receive at the moment it wants to enter a blocked area. The group could for example be sent to the closest exit.

Within this object we could also find the Exit Table, which lists all exits in the entire model. This table will be used when a group determines which exit is the closest exit.

### Area Emergency Control Object

During an emergency scenario, each area needs to contain an Area Emergency Control object, that controls the local impact of the emergency. If the global Emergency Control gives a signal, this object executes the blocking of the area, it sets the resistance to a higher value and the handling times to zero, since people will not have to wait at customs, check-in desks et cetera. It also removes the groups waiting to enter the area at the moment an emergency breaks out. This way they will be able to execute their new script, which might not require that the groups enter the area they are currently waiting for.

This object does not have any local user input.

### Area Evacuation Control Object

Next to the Area Emergency Control, each area possesses an Area Evacuation Control object as well. At the outbreak of an emergency, this object checks whether groups are located in the area, lists these groups, and tells them to escape.

First of all, the Area Evacuation Control provides groups within the area with a pre-movement time. During this pre-movement time, each individual continues doing what he does already. The pre-movement time, if locally assigned, depends on the area characteristics and is user-defined by means of the area table in the global Evacuation Control object.

After the pre-movement time, the Area Evacuation Control assigns a new script to the groups, so they will individually move towards an exit. This too can be done according to a local or global script assignment table, as indicated in the Evacuation Control. The possible scripts will be described later.

In case a group meets a blocked area, it will be assigned a new script by the local reassign method. At the moment a group requests to enter this emergency affected area, this method is run. The shortest path is calculated considering the new situation including the blockages, and a new evacuation script is assigned.

The local user input of this object consists of the local script assignment table, which determines the distribution of evacuation scripts. In order to use the local script assign tables, the user should pick the local script assign option in the Evacuation Control dialog.

### Doorway Object and Emergency Exit Object

An object with the functionalities of a doorway has been created. This object can be seen as a resource that contains a process time, depending on the width of the doorway and a specific flow. This object can be implemented in the different existing networks, such as piers, lobbies et cetera.

For doors with a width larger than one metre, the process time of the doorway resource depends on the door width and the specific flow, according to the following formula:

$$\text{Flow time} = \text{Capacity} / (\text{Specific flow} * \text{Door width}) \qquad (1)$$

in which the value for the specific flow is user defined and the capacity is determined by:

$$\text{Capacity} = \text{floor}\,(\text{Door width} / \text{width per person}) \qquad (2)$$

According to the literature research (chapter 6.2 ), the default value used in the experiments will be 1.5 persons per meter per second.

For narrower doors, other formulas should be used. It is recommended to improve the capabilities of this doorway object, if we want to create doorways, which meet these characteristics.

As can be seen in formula (2), the capacity of the area (which is the number of persons that can be simultaneously handled time by the resource), represents the number of persons that can pass the doorway at the same time. The default value for the width per person is 0.45 m in this model.

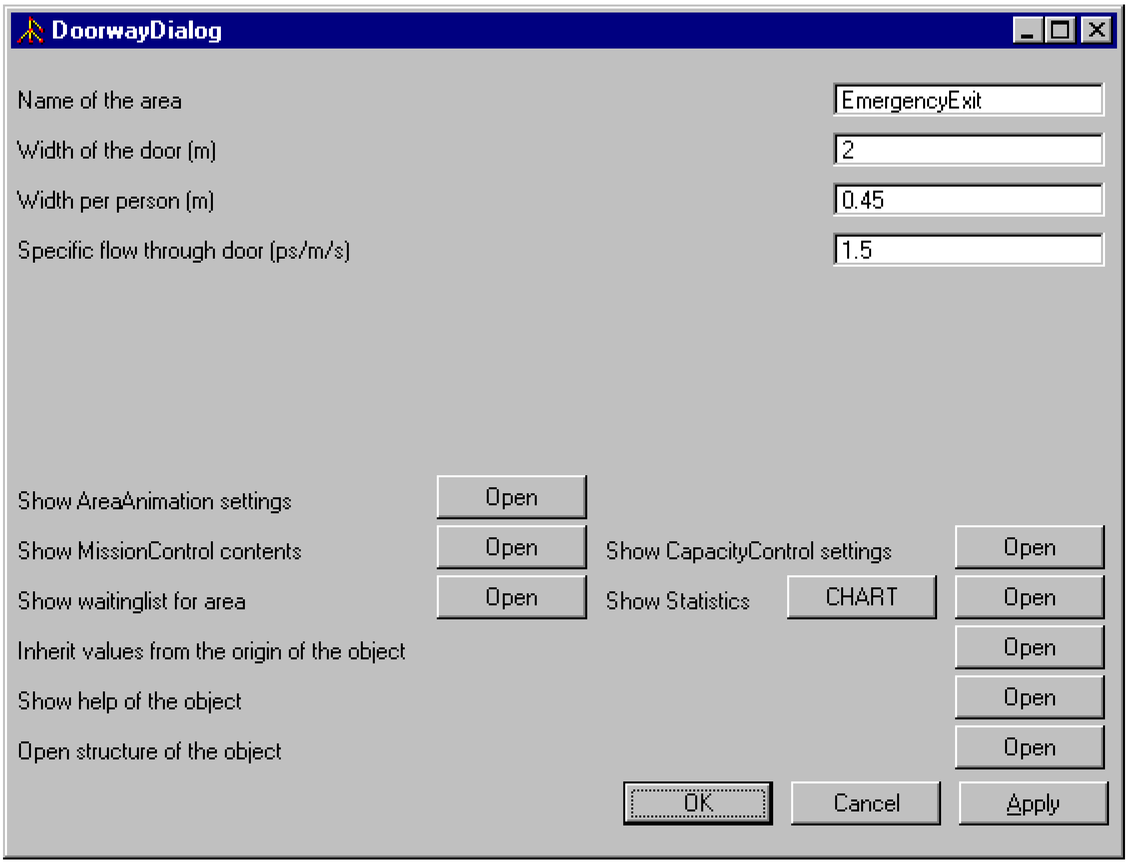


*Figure 12-6: The user input of the Doorway object.*

In the literature is stated that these formulas are only valid for exits with a minimum exit width of one meter. In this model, though, it is possible to enter door widths of less than this minimum value. In the future the object should be developed so it can also handle smaller widths.

The dialog box offers the possibility to enter the relevant parameters of the Doorway object (Figure 12-6).

The Emergency Exit object is a more advanced doorway. It represents all doorways used as exit during the evacuation. The Emergency Exit connects the areas inside the building to the areas outside the building. By using the Emergency Exit object, all egress possibilities in a terminal building can be shown in the model. The difference between a Doorway and an Emergency Exit is that Emergency Exits register that a group enters or leaves the building. When a group enters the terminal building, the group will get assigned the Exit through which it enters as its familiar exit; when the group leaves, the group evacuation time, the building evacuation time, et cetera will be registered.

In our literature search we concluded that also other aspects of the escape routes were relevant. In the future we could therefore expand the capabilities of this objects, for example adding an attractiveness attribute, describing the visibility of, and the clarity of the signage towards the escape route.

### Emergency Scripts

From the literature research we know, that occupants choose their escape route individually, based upon received cues, their current position, individual characteristics, and social behaviour. A few different possibilities have been taken into account in this model:

- Groups flee towards the closest exit
- Groups flee towards a familiar exit
- Groups flee towards one user-defined exit

For meeting these possibilities, different evacuation scripts have been created, respectively “EvacScrClosestExit”, “EvacScrFamiliarExit”, and “EvacScrChosenExit”. The script of a group prescribes its behaviour. This way, it is possible to model an evacuation in which occupants originating in the same area will try to escape through different exits, depending on personal characteristics, area characteristics, or a random distribution. At the moment, personal characteristics are not taken into account. This could be implemented in the future.

In future, the scripts can be differentiated on other levels too. We could for example write scripts in which occupants start searching for their luggage or for group members, before showing flight behaviour. The scripts are shown in Appendix V.

### Script Statement “SetDestClosestExit”

In order to be able to direct a group towards the closest exit, the script statement “SetDestClosestExit” has been introduced. If a script contains a line referring to this script statement, such as the script called “EvacScrClosestExit”, the group will read the possible exits from the Exit Table in the Evacuation Control. Using the Distance Table in the Area Direction, the group determines to which of the exit objects is the nearest one.

*Table 12-1: Relevant evacuation simulation output, and the tables that will provide this output*

| **Global output**<br>Evacuation Statistics Table | **Local output**<br>Area Statistics Table<br>Exit Statistics Table | **Group output**<br>Group Control Details Table |
|---|---|---|
| • Total building evacuation time (time between start emergency and last evacuee left)<br>• Time first group leaves the building<br>• Time last group leaves the building<br>• Number of people that left the building successfully<br>• Number of groups trapped<br>• Graphic with number of groups evacuated over time | • Time first group passes<br>• Time last group passes<br>• Average queue length<br>• Maximum queue length<br>• Average queue waiting time<br>• Maximum queue waiting time<br>• Number of groups handled<br>• Number of groups trapped<br>• Graphic with number of groups left over time | • Individual evacuation time<br>• Waiting time at bottlenecks<br>• Individual pre-movement time<br>• Initial position when evacuation started<br>• Distance travelled<br>• Route taken<br>• Exit taken<br>• Trapped |

## Evacuation Statistics Object

The relevant output variables of this simulation model can be subdivided into three levels: global output, local output, and group output. The global output deals with the statistics concerning the entire evacuation, such as the total evacuation time of the building, or the number of casualties. The local output focuses on statistics gathered by single objects, representing a part of the built environment, such as a walk area or an emergency exit. The group output registers the individual performance of the groups, e.g. individual pre-movement time. The output variables relevant for evacuation analysis are presented Table 12-1.

The evacuation statistics object has been created to give a quick view on the relevant output variables of the emergency simulation. Within this object, four tables are visible: the Evacuation Stats Table shows the global output, the Exit Stats Table shows the results of all exits in the model, the Doorway Table shows the statistics of the internal doorways, whereas the Area Table lists the relevant statistics of all areas in the model. The group output can be found in the existing Group Control object, inserting the relevant attributes into the User Attribute Table.

In order to identify the main bottlenecks in the model, also during non-emergency situations, it is useful to centralise the area statistics. Information on the waiting times and queue length should be collected in one central area statistics table. Before we created this object, the area statistics were only reachable via the area itself. An even better solution would be to animate the maximum area density by means of coloured areas on the terminal layout.

## Emergency Toolbar

To make the new emergency-related objects more accessible to the user, a new toolbar has been introduced among the existing toolbars (Figure 12-7). The meaning of the different icons is listed in Appendix VI.

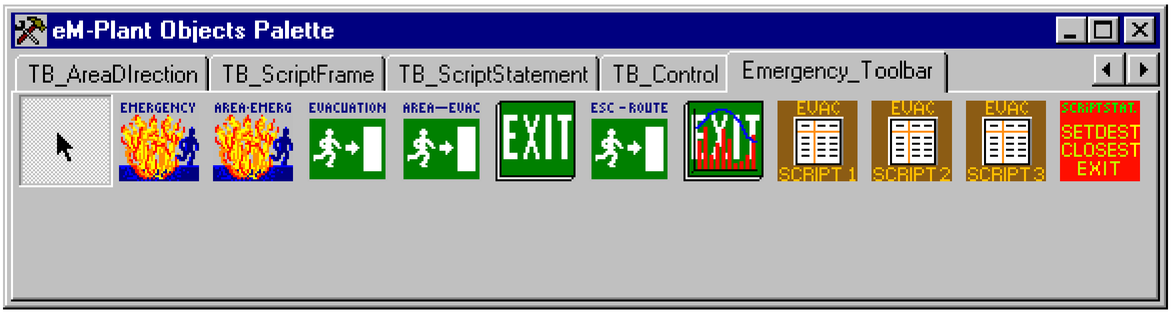



*Figure 12-7: The emergency toolbar.*

## *12.3 Events*

This paragraph focuses on the consequence of events that represent the emergency within the Airport Passenger Library. An event can for example be a change of an object's attribute, an object calling a method, et cetera. Often, events represent interaction between objects. The event order can be clarified with an interaction model, as can be found in Appendix VI.

At the beginning, the Emergency Control initiates the emergency at the time it breaks out. According to the Emergency Growth table, in which the moments on which areas will be blocked are listed, certain areas are affected by the emergency. These areas will be blocked, and cannot be used by the groups anymore.

After a certain user-defined detection time, the Emergency Control object triggers the Evacuation Control object, realising that the groups in the model will prepare to evacuate. The generation of new groups will be stopped, so no one enters the building from this moment.

Then, the areas are told to start the evacuation. Each area will list the groups currently present within this area, and randomly assign them relevant attributes, a pre-movement time, and an emergency script. By making the area assign the pre-movement times and the script, a more representative distribution can be realised then by assigning them globally. This way a specific area-dependent pre-movement time distribution can be used valid for processes and activities performed in this very area. Besides, the emergency script distribution can also be adapted to the area characteristics.

When groups have been assigned a pre-movement time and a new script, they will delay during the pre-movement time and then start to execute the new script. When a group has gone through an emergency exit, statistics are registered and the group will be deleted from the system.

## *12.4 Simplifications and assumptions*

We are not able to simulate all aspects of reality. Therefore some simplifications and assumptions have been made. In the following, the most important ones not yet mentioned, are listed and justified.

### User defines parameters

The user of the evacuation simulation tool must define most of the evacuation parameters, such as specific flow through doors, the pre-movement time and the route choice distributions through the building.

With regards to pre-movement time and route choice, this means, that he is responsible for indirectly taking into account the effects of signage, commitment to activities, number of personnel available, cue type, et cetera, since this is not explicitly taken into account by the model. This way, we would like to avoid that the model becomes a black box, in which the relations cannot be easily changed by the user. Beside this, most of the before mentioned aspects are too complex to quantify, and should therefore be varied by means of scenario-thinking.

The problem, of course, is that this requires very specific knowledge of the user, since he is supposed to be able to judge the influence of certain aspects on other aspects.

### Only passengers are modelled

Only passengers are modelled, though we concluded in the previous chapters that personnel could play a significant role in the evacuation of terminal buildings. The influence of instructions by the personnel can be included in the pre-movement time distributions that can be area specific. This way, of course, only the effect of the directions is taken into account, not the effect of a larger number of occupants within the terminal.

### All groups evacuate

Based upon Canter's model applied to airport terminals, we assumed that all passengers evacuate, and no one fights the emergency. Terminal buildings are usually very large, and the majority of the occupants are not positioned close to the emergency. Besides, groups expect emergency resources to fight the emergency. The small amount of heroes among passengers is left out of consideration.

### Luggage is not modelled

Groups do not have any luggage, and cannot leave or take luggage, though especially within terminal buildings it could be interesting to take the influence of luggage on flight behaviour into account. Carrying suitcases decreases the speed of occupants, and searching luggage pieces might make the pre-movement time increase. In the future, it is recommended to take the effect of luggage into account.

### Group members stay together during evacuation

Given the existing library, it was hard to divide groups into individual group members, so they could flee in different directions. Therefore, in this model group members stay together during escape. This is not a very unrealistic assumption, as it is proved that a lot of groups, especially those consisting of families, start searching for other group members before escaping. The role model within a group will often lead to one decision-maker deciding which escape route to follow.

The alternative would be to model each individual as a separate group. The disadvantage of this solution is that family members that normally travel together, are torn apart and might arrive at different moments and move in a different manner through the terminal.

### No hazard effects are modelled

Since the emergency growth model is not very sophisticated, it is not known when groups will suffer from what emergency effects. Therefore, no people die from the emergency. There is one situation in which groups do not manage to get out of the building, which is when it is surrounded by blocked areas, and therefore trapped. All other groups can be evacuated, no matter how long it takes them.

### Blocking does not affect those in area

If an area gets blocked, the people already within the area are still being processed, without change of handling time. If, though, they notice that the next area they want to enter is blocked too, they are considered to be trapped.

### Groups do not have an overview

A group is alerted about the blocking of an area, at the moment it wants to enter. If groups meet a blocked area, they will be re-routed towards closest exit. This means that groups cannot get informed by other groups, or notice an emergency from a distance. Another consequence is that groups cannot enter a blocked area during the detection time either. The situation, in which groups want to enter an area because they do not know it is affected by an emergency, is not incorporated in the model.

On the other hand, in case we choose to send the occupants towards the closest exit, this means that the occupant exactly knows which exit is the closest. In this case the occupant does have an overview.

### Group creation stops if emergency breaks out

At the moment the emergency breaks out, no more groups enter the building, though emergency might not be detected yet. This is done, to be able to collect statistics easily.

### No interaction between groups

The groups do not have influence on other groups, apart from the fact that they occupy space in an area. This means, that groups cannot warn each other, do not hinder each other by obstructing the way, et cetera. In future modelling, the incorporation of interaction is recommended.

# 13 Constructing an evacuation model

In order to simulate a real case, we have to construct a model of the situation. In this chapter we will describe the process of simulating emergency evacuation in the Airport Passenger Library, using the new emergency and evacuation objects.

## 13.1 Model construction

The construction of the basic model of an airport is of great importance and depends highly upon the objective of the simulation study. A simulation study could for example be part of the design process of a new terminal building, or show the effects of modifications of the existing structure. For each terminal simulation, we could distinguish a number of modelling steps:

1. **Terminal layout modelling**

2. **Flight schedule modelling**

3. **Population characteristics modelling**

4. **Population arrival time distributions modelling**

5. **Normal script design modelling**

These five steps are to be executed whether or not an emergency scenario is to be simulated. Since these steps are related to the already available features of the Airport Passenger Library, we will not go deep into this. For more specific information on model building in the Airport Passenger Library, we refer to Valentin.[97] In order to be able to simulate evacuations, specific additional emergency modelling steps are necessary. This will be described in the next paragraph.

## 13.2 Emergency modelling

During the emergency modelling, we add emergency objects to the terminal building, and we define the parameters that are of importance during emergencies. The important steps are the following:

1. **Emergency exit modelling**
   Determine the location of the emergency exits, and the properties of the emergency exits, e.g. specific flow and door width.

2. **Emergency growth modelling**
   Model a scenario of a possible emergency by specifying the areas to be affected, and the time sequence of this affection.

3. **Pre-movement time assignment modelling**
   Decide whether to use a local or global pre-movement time assignment, and specify the pre-movement time distributions, based upon signage, commitment to the

[97] Valentin, E. (2001), Reference Manual Airport Passenger Library, TU Delft, faculty of TBM

activity performed in this area, cue type, directions by personnel, et cetera, as sketched in Appendix VI.

4. **Evacuation script assignment modelling**
   Decide on local or global script assignment, write the evacuation scripts, and define a distribution which tells which percentage of occupants uses which scripts.

5. **Emergency procedure modelling**
   Consider the procedures within the terminal, e.g. centrally controlled exits, or always accessible exits, escape possibilities through the customs, security controls, step-wise evacuation or integral evacuation, et cetera.

6. **Verification and validation of the model**
   Check the input parameters, and do experimental runs in order to see if the model of this very airport is valid.

7. **Design of scenario variations**
   Design scenarios by specifying relevant parameters that will be changed during simulation experiments.

8. **Running experiments**
   Run the different scenarios, interpret the results and see if solutions to the problems could be suggested, and new scenarios are necessary.

We would like to emphasise that most parameters we have to specify, depend on other parameters, which might be variable as well. As shown previously (Appendix VIII-Appendix X), the pre-movement time is influenced by the local warning signals, such as directional information given by staff members. We could therefore define scenarios in which these staff members are present in an area or not, resulting in a higher or lower local pre-movement time.

In this model, many parameters are user defined. This puts a large responsibility on the user of the model. During the modelling phase, the user has to determine the walking speeds distributions, distributions concerning pre-movement times, the emergency growth, the specific flow values of doorway objects, et cetera. This has been done, in order to avoid a model that operates as a black box, using relations that are not directly clear to the user of the model.

# 14 Verification and Validation: Safe Town Airport

In this chapter, the validation of the new building blocks will be described. Before we can use this evacuation tool in practice, we have to ensure that it does what it is supposed to do. Each element of the simulation, as well as the combination of elements, should operate properly.

Galea[98] distinguishes the following four validation steps, which we will explain, discuss, and apply below:

- component testing
- functional validation
- qualitative validation
- quantitative validation

Before we describe these validation steps, we will introduce the Safe Town Airport model, which will help us during the validation.

## 14.1 *Safe Town Airport*

The terminal of Safe Town airport consists of a very basic layout with one entrance, two check-in desks, one passport check with a capacity of two, one gate, and three emergency exits. The 'default' Safe Town-model consists of representative process times and default choices. A schematic view of the terminal layout is presented in Figure 14-1. The model construction steps can be found in Appendix XI.

The main advantage of using this small model, is that it is easy to keep an overview. Not many passengers are created and only a small number of areas are available. The behaviour, though, is representative for larger models. Besides, the time it takes to run an experiment is significantly shorter for small models. For the validation phase, in which we would like to run numerous experiments, this is a big advantage.

Application to models on a larger scale is presented in the next chapter.

## 14.2 *Component testing*

Component testing, or component verification, is the process of checking whether each individual component of the model works the way it is supposed to work. It has for example been checked, whether the code of the model contains no errors and represents the conceptual models, whether the calculation of the output is done correctly, and whether the appropriate parameters are used. Component testing is an ongoing activity during the model building. We will discuss the most important components we tested, namely the doorway and the emergency growth.

[98] Galea, E.R.(1997), Validation of Evacuation Models

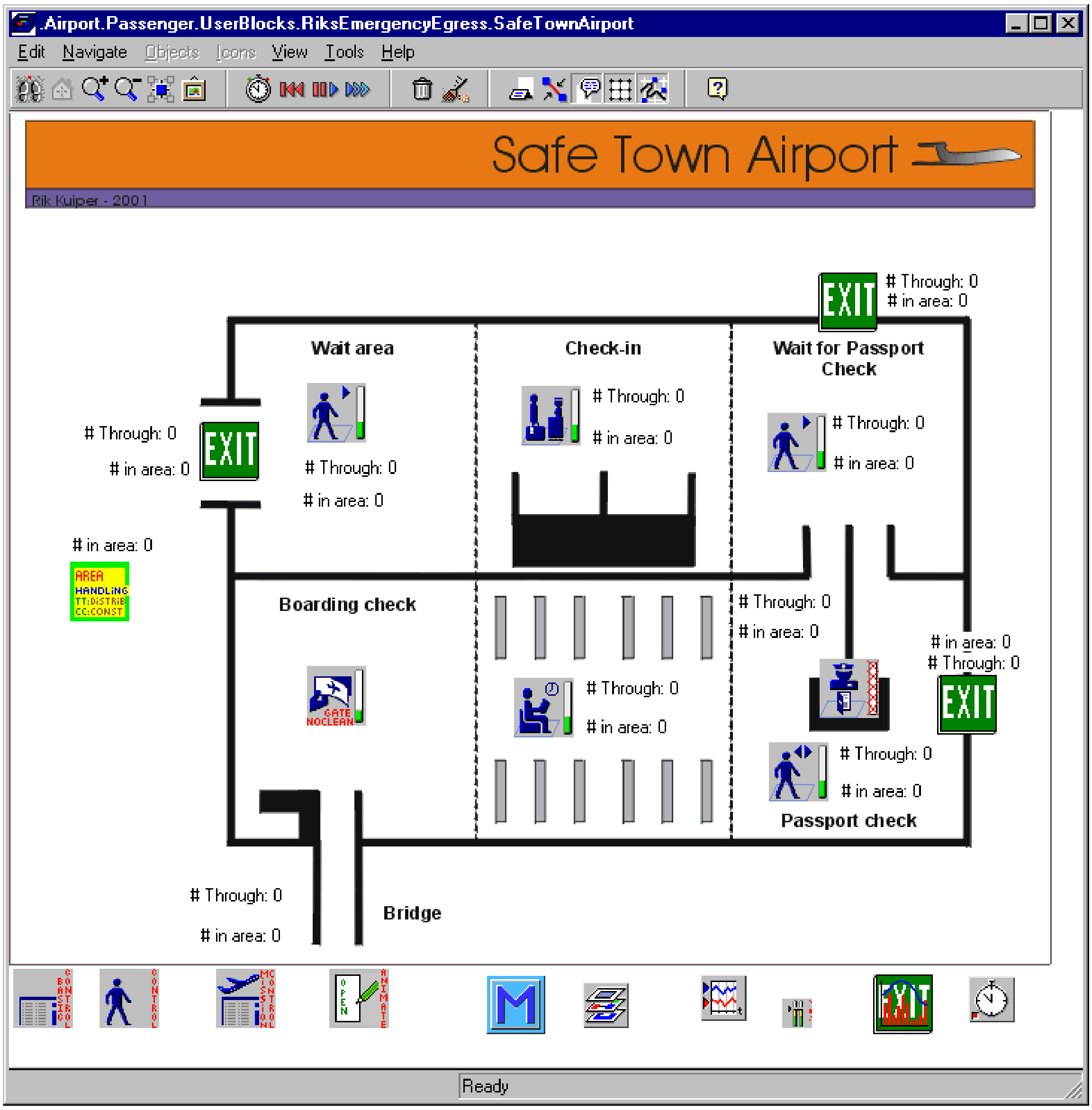



*Figure 14-1: Schematic view of the Safe Town Airport model.*

## Doorway

For this evacuation model, the Doorway object has been tested separately, to check whether the process times were calculated correctly. A small model has been built, consisting of an entrance, a doorway and an exit. Only the doorway object had a process time, so the entire time a group was in the system consisted of waiting to get through the door and getting through the door itself.

The validation step showed that all group members leave the door at the same time, since they are processed as a group. There is one cumulative process time for all group members. This means that if the first group member in reality has already left the building, in the simulation he is 'kept inside' until the last group member passed the exit. This causes a deviation for the individuals, presenting individual and average evacuation times to be slightly higher than in reality.

### Emergency growth

The growth of the emergency according to the user-defined Emergency Growth table has been tested separately from the rest of the model. It has been checked whether the areas were blocked at the moment they were supposed to be blocked, and what happened to the groups inside these areas and those waiting to enter the area. It appeared that groups waiting to enter a blocked area were not re-routed, and stayed where they were. This problem has been solved. Another important aspect of the emergency growth was to return the original values to the object when a new simulation run is executed. This proved to work correctly.

## *14.3 Functional validation*

The functional validation involves checking that the model possesses the ability to perform the processes it has been created for. The purpose of building an evacuation functionality into the existing Airport Passenger Library, as defined in chapter 3, was to be able to test the emergency safety of passenger terminal designs.

During the construction of the new building blocks we have aimed to serve this purpose. Therefore, the conceptual models and the case studies have been discussed with experts at TNO Centre for Fire Research and Schiphol. In the future, we should perform more case studies, and show the models to other experts, so we will be able to assess if we succeeded, and if the model is functionally valid.

## *14.4 Qualitative validation*

During the qualitative validation, model predictions are compared with the expectations. We will pose rational expectations and see if the model meets these expectations. Strange model behaviour can appear, or underlying assumptions could turn out to be wrong.

We distinguish verification and structural validation. Both will be discussed below. Please note that we consider the existing Airport Passenger Library objects to be correct and validated. Therefore, we have not subjected the existing objects and parameters to a new validation.

### Verification

For this part of the qualitative validation, we have used the model of the fictive airport of Safe Town. By consequently varying some other user-defined parameters, ceteris paribus, we have been testing if the concepts and relationships were correctly implemented. We have been using the following cases:

**Script assignment**

- All occupants get their script assigned locally
- All occupants get their script assigned globally

**Pre-movement time assignment**

- Local pre-movement time assignment
- Global pre-movement time assignment

**Exit choice**

- All occupants use the familiar exit
- All occupants use the closest exit

- Some occupants use the familiar exit, others use the closest exit

**Growth scenario of the emergency**
- Emergency with growth
- Emergency without normal growth
- Emergency with quick growth so people get trapped

An interesting and surprising result of this verification step is that we found that evacuation of this Safe Town Airport setting is quicker when all people leave through the entrance (scenario 6), than if they all use the closest exit (scenario 1). This shows that evacuation time not only depends on the proximity of exits, but also on the capacity of this exit.

Another remark should be made, considering the scenarios, which contain emergency growth. If an emergency is growing, groups might encounter the hazard before the an alarm has sounded. This means, that they start to evacuate even before the detection time is over.

The results of this validation step can be found in Appendix XII.

## Structural validation

One part of the qualitative validation is the structural validation. Structural validation can be done by subjecting the model to extreme impulses, like very small or very large input variables, to see if the model reacts like it is supposed to react. For example, we expect shorter evacuation times when groups use the closest exit or when the doors are wide, than if groups respectively use an exit further away or have to leave through narrow doorways. The absolute values are not valuable. Or one could for example test the simulation by running a scenario in which only one person has to be evacuated, and another scenario with an extreme amount of people to be evacuated. [99]

By using the default Safe Town Airport model, consequently varying some user-defined parameters, ceteris paribus, we have been testing the following cases for this structural validation:

**Population size**
- Small population
- Large population

**Properties of the population**
- Population with low walking speeds
- Population with high walking speeds

**Properties of the emergency exits**
- Doorways with large specific flow value
- Doorways with low specific flow value
- Doorways with large width
- Doorways with small width

These scenarios have been executed, and most of the scenarios finally produced the results we expected, though some of the features had to be improved. For example, a solution had to be found for groups that were located outside the terminal at the moment

[99] Faculteit Techniek, Bestuur en Management; Discrete Modellen, dictaat TB232 deel 2, p.162; maart 2000

the emergency starts. At first, they tended to go to the entrance, because this was the closest Emergency Exit object. Of course, though, they should not claim any exit capacity, since they are already outside the building.

After this validation step, the model can be considered structurally valid. We should emphasise that these are results of a *qualitative* validation, which means that one should only pay attention to the fact that one evacuation time is larger than the other, that passengers leave through the right exit, that queues are longer, or that passengers do not disappear.

The results of this validation step can be found in Appendix XII.

## 14.5 Quantitative validation

Quantitative validation generally involves comparing the model output to a set of existing real time data or to data coming forth from other simulation packages. By means of statistical tests can be measured if the model is valid. The aim of quantitative validation is to demonstrate that the model is capable of reproducing measured behaviour.

As mentioned before, this part of the validation is by no means an easy task, because reliable and complete data sets of emergency evacuations are rare and the processes described are complex. In the future it is recommendable to gain quantitative data of real evacuations, by instructing the airport management teams to register the important parameters instantly, when a real evacuation is being performed, or to offer the available video footages to researchers. These data are of immense importance for the development of evacuation models, and through this for the increase of safety within airport terminals.

The comparison of model results with evacuation exercises is not always a good alternative. The International Maritime Organization[100] states for example, that evacuation exercises often produce better results than real evacuations.

Galea[101] mentions also the possibility of quantitative validation by blind predictions. Before the modeller has access to the results, he has to perform predictions on the outcomes. The acceptance level of this type of validation, though, is significantly lower. Nevertheless, since we do not have data sets of airport terminal evacuations, this is the only way we could try to validate the model. In the next chapter, using the Schiphol F-pier case, we will try to execute the quantitative validation.

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[100] IMO (2000); Recommendation on Evacuation Analysis for Passenger Ships and High-Speed Passenger Craft – Passenger Vessel Evacuation Analysis

[101] Galea, E.R., M. Owen, S. Gwynne (1999); Principles and Practice of Evacuation Modelling – A Collection of Lecture Notes for a Short Course; 2nd Edition

# 15 Experimentation: the Schiphol case

In this phase, a more realistic case will be executed in order to see if the model works correctly. For these purposes, we have used the previously constructed model of Amsterdam Airport Schiphol. This case study can be considered to be an iterative validation step. The errors in the model have been used as feedback to the previous model building phase. Based upon them, adjustments have been made.

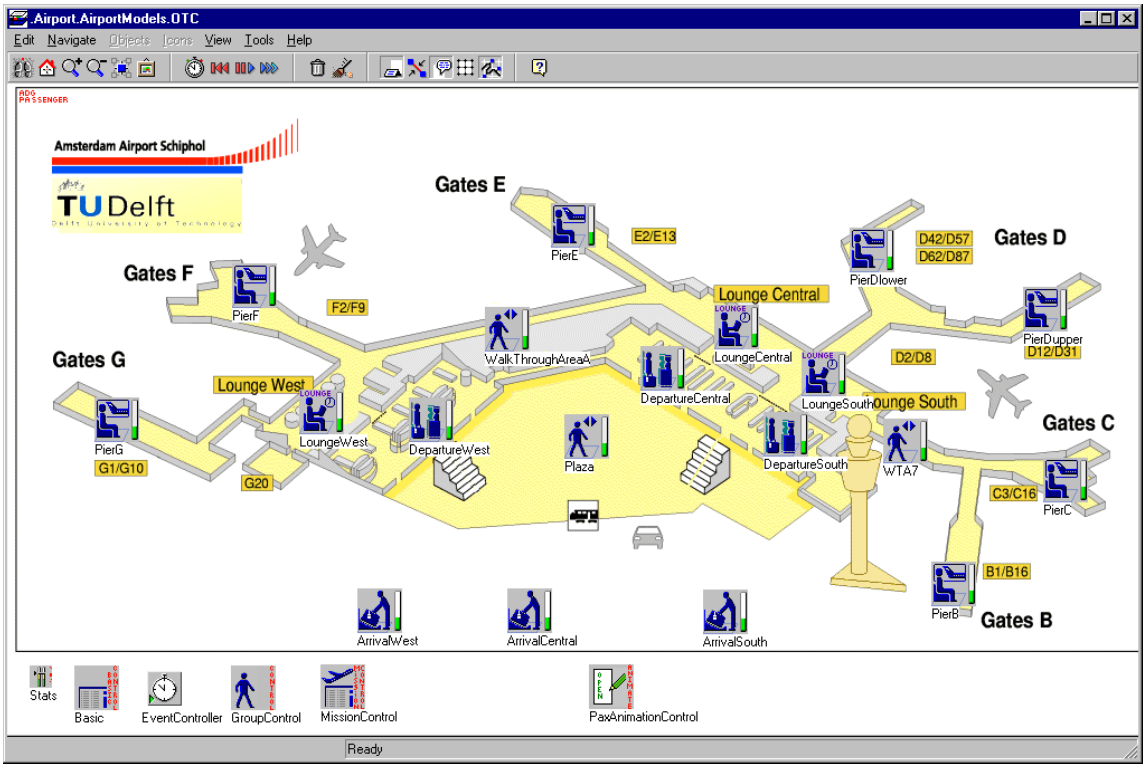


*Figure 15-1: The existing Schiphol simulation model, built using the Airport Passenger Library.*

## 15.1 Objective of the Schiphol case

The second prove of concept, after the Safe Town model, was executed using the existing Amsterdam Airport Schiphol model, built by Edwin Valentin at Delft University of Technology (Figure 15-1). This model consists of the public zones of the entire terminal layout, representative flight schedules, group generation dependent on flight characteristics, et cetera. The model was previously used in order to simulate the normal operation on the airport, varying for example the location of the security control units.

Considering the time constraints, we decided to limit this research to the F-pier, since this sub-model already contained a working animation. The objective of this small case study will be to:

> *Show the working of an evacuation model, and reveal the main bottlenecks during an evacuation of the F-pier at Schiphol Airport.*

In the following we will describe the construction of the basic simulation and the emergency modelling.

## 15.2 Model construction

In this paragraph we will follow the previously described step order to structure the simulation of an airport terminal. Only the most important concepts will be discussed in this chapter; for details concerning the all input variables, we refer to Appendix XIII.

### Terminal layout modelling

The F-pier of Amsterdam Airport Schiphol consists of eight gates, connected to boarding bridges. At the used floor plans, we still see the security check infrastructure at the gates. Currently, though, the clean check at Schiphol Airport is performed centrally, which means that the existing x-ray machines are not in use anymore, and therefore not modelled.

Schiphol provided the required information concerning the layout, the location of the exits, and the escape routes.[102]

### Flight schedule modelling

The population during this simulation exists only of departing passengers, in order not to make the simulation too complex. We justify this assumption by mentioning the fact that departing passengers stay in the piers for a longer time than arriving passengers. Arriving passengers leave their aircraft, walk through the bridge into the pier and head directly for the reclaim area or their connecting flight. Departing passengers arrive earlier than their flight actually leaves, and stay in the wait areas until they are requested to board.

From a study by Arends[103] we learn that around 2500 passengers are in the F-pier during peak hours. For our evacuation simulation, we planned the emergency at a moment that over 2000 persons were in the building, all waiting for their departing flight. Their distribution within the pier, generated by our model, is considered to be representative.

### Population characteristics modelling

The population consists of groups of one to three persons. As mentioned before, all passengers are departing passengers. The occupants have walking speeds between 0.635 and 1.1778 meter per second, triangularly distributed, as used by Arends.[103]

### Population arrival time distributions modelling

The arrival time distribution refers to the moment that the passengers arrive at the foot of the F-pier. All passengers arrive according to the same arrival timetable. Since the data we have, reflect the arrival time distribution for arrival at the gates, and not arrival at the pier, we had to reconsider the arrival timetable. We added an average time of 200

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[102] Schiphol Group (2000); Beveiliging ontruimingsplan bedrijfshulpverlening – terminal floor-plans
[103] D. Arends; Using Object-oriented Simulation for a Quantitative Approach of the Terminal Concepts; final thesis Delft University of Technology, 1999

seconds, which should be representative for the time it takes to walk from the foot of the pier to a gate.

### Script modelling

A very basic script will be used to describe the passenger behaviour during normal operations, i.e. before the emergency breaks out. Departing passengers do not walk through the entire terminal building, but are created at the foot of the pier, in the Group Generation area. From there, they head for their gate, wait for boarding and enter their plane.

## 15.3 *Emergency modelling*

In this paragraph we will describe the modelling of the relevant parameters for an emergency and evacuation simulation. Before being able to execute an evacuation scenario, the emergency exits in the terminal had to be added to the model, as well as the new Emergency Control, Evacuation Control and Evacuation Statistics objects.

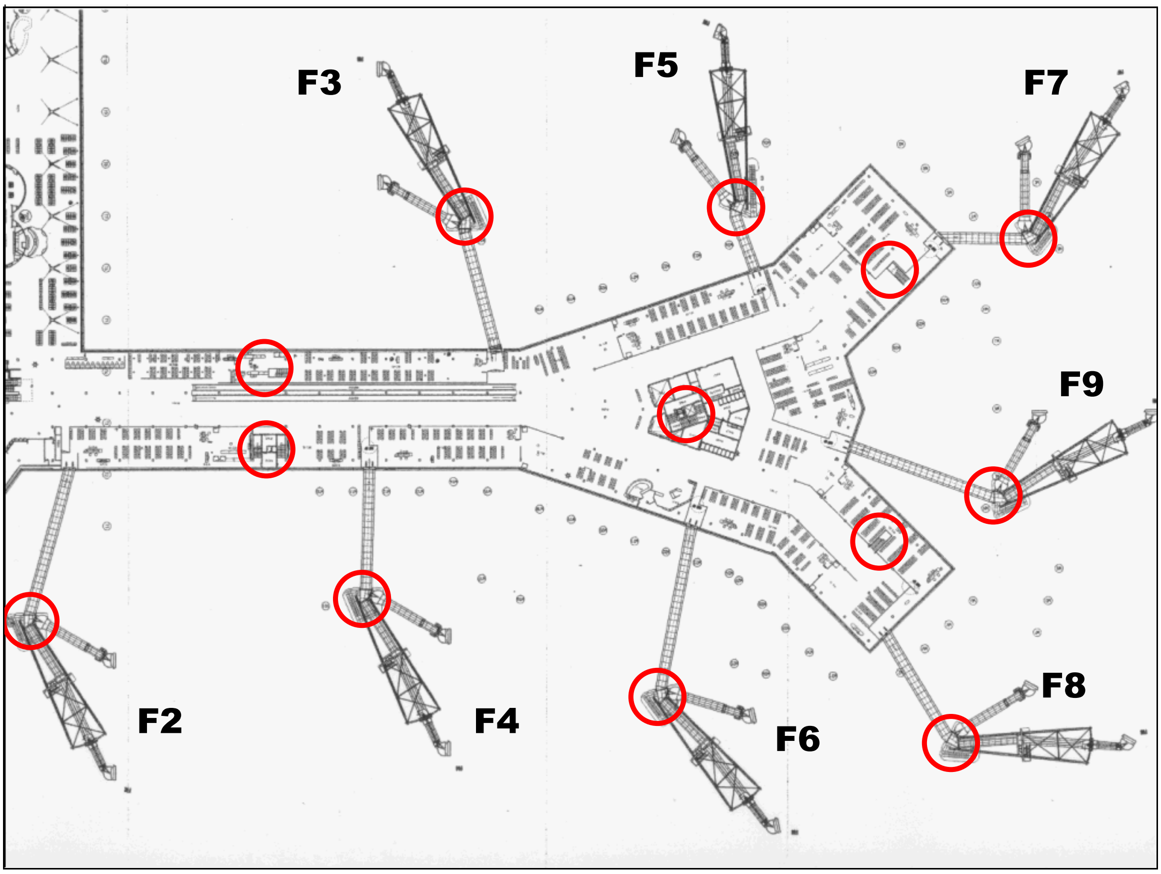


*Figure 15-2: Emergency exits in terminal layout of the F-pier at Schiphol.*

### Emergency exit modelling

In the layout of the first floor of this pier, which is the traffic area for both arriving and departing passengers, we can distinguish a number of emergency exits. As we can see in Figure 15-2, two of them are situated in the two fingers of the pier, while one central emergency staircase is located at the position where the pier splits into two fingers. Two further staircases can be found in the middle of the pier, near gates 3 and 4.

All escape routes consist of staircases that lead to the ground level, on which a door towards the apron is located. Since the emergency exits are located at the end of escape routes, we have decided to create a new compound area, i.e. a frequently used constellation of other areas, collected in one frame. This compound area, called “Escape route”, consists of a walking area, a staircase, another walking area and finally an emergency exit. The widths of these corridors and emergency exits are various, as well as the parameters, such as walking distance, within the escape route object. A representation of the Escape Route frame can be found in Appendix XIV.

The implementation of the staircase raised some problems, since no staircase object was available in the existing library. We decided to use normal walk areas, although this means some aspects of reality were not taken into account. It is recommended for the future, to develop a staircase object.

Beside the emergency exits, occupants could flee through the bridges towards the aeroplane or the apron. On the terminal-side near the foot of the pier, there are roll-down shutters, which create fire compartments. Escaping groups can pass these roll-down shutters using an emergency doorway. The shutters have not been implemented in the model.

A representation of the adapted F-pier model can be found in Figure 15-3.

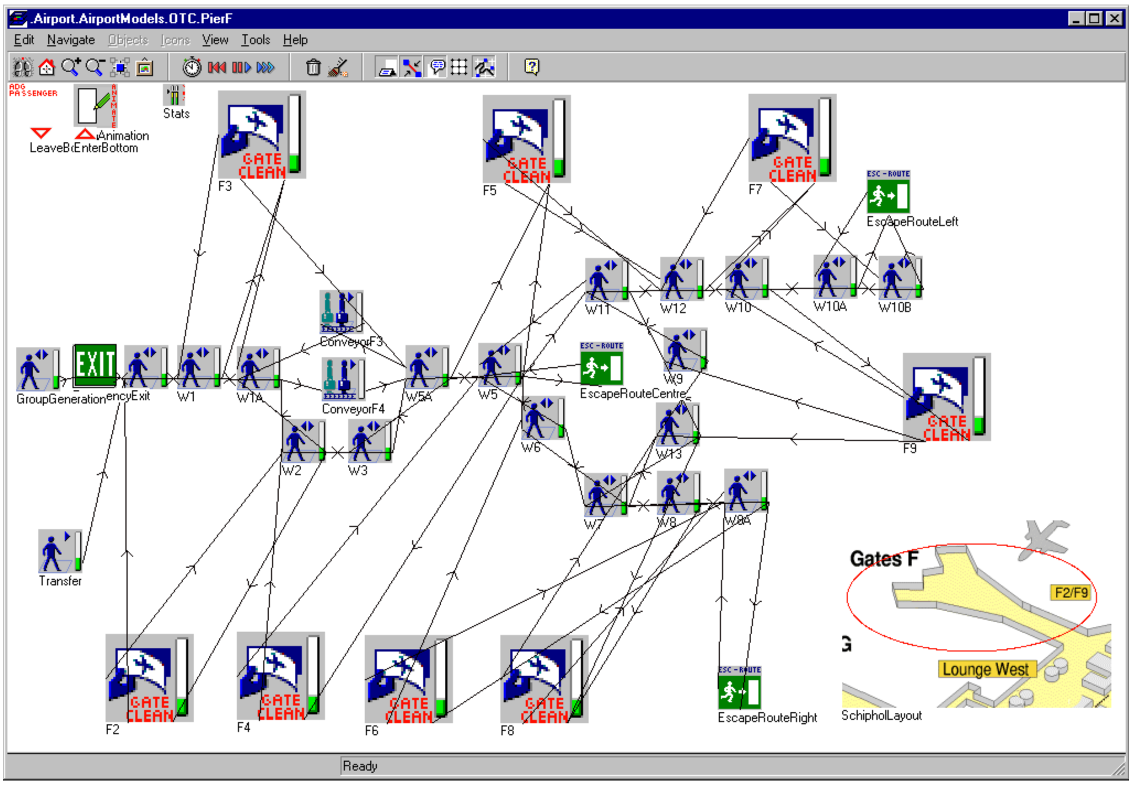


*Figure 15-3: Model of the F-pier. The green objects represent the escape routes, the Exit-sign the entrance.*

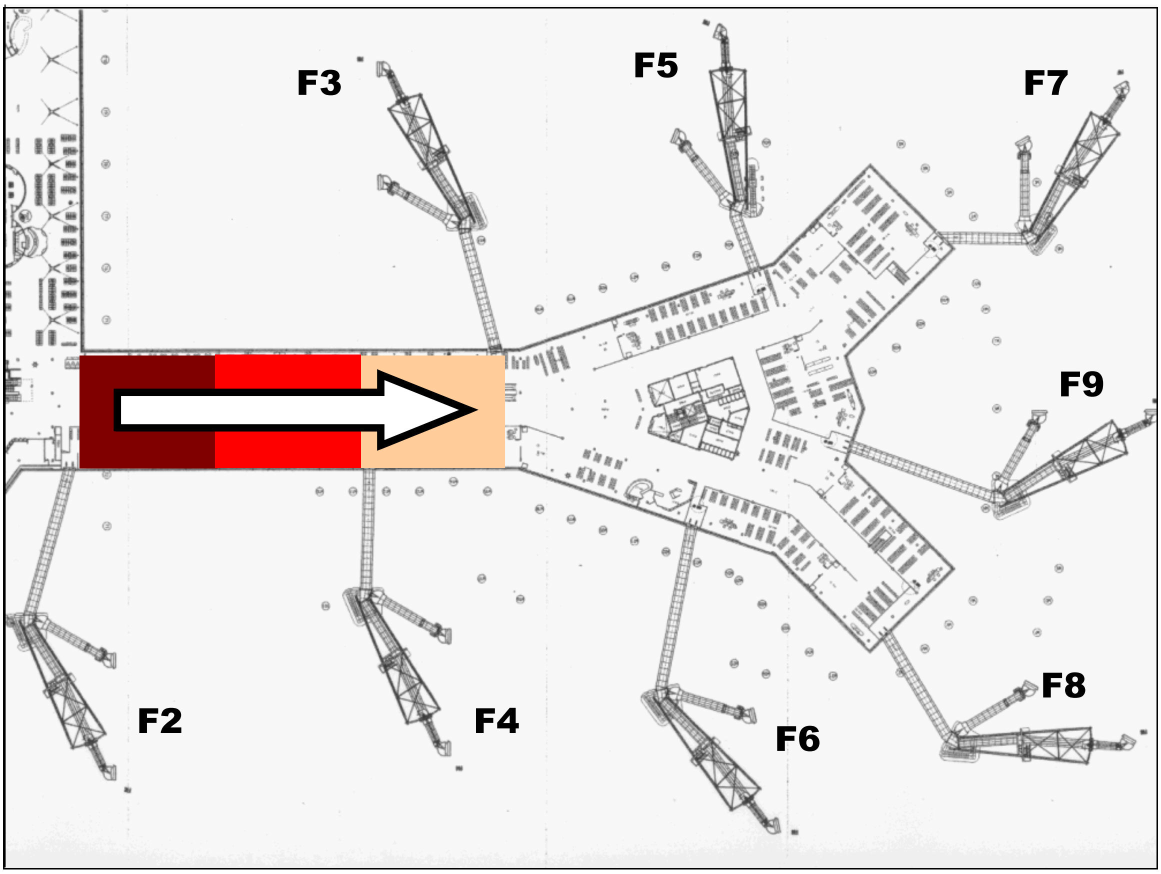


*Figure 15-4: Schematic view of the emergency growth scenario, starting at the foot of the pier, developing towards the head of the pier.*

### Emergency growth modelling

For this case, we have made up a fire scenario, starting in the foot of the pier near the gates F2 and F3, growing in the direction of the other F-gates, as can be seen in Figure 15-4. This way, the emergency has a major impact on the passengers heading towards the familiar, since they cannot use the routes, which they used when they entered.

### Pre-movement time assignment modelling

The pre-movement time in this case will depend on the proximity to the emergency. The occupants close to the emergency will need less time to become aware of the situation, those at a distance will first notice the escaping people, then the fire itself. The pre-movement times are therefore locally assigned.

Due to instruction by the personnel, the values of the pre-movement time distributions vary, dependent on the scenarios, which will be discussed later.

### Evacuation script assignment modelling

For this case, we will use the standard scripts, constructed for the Airport Passenger Library, as described in chapter 12. That means, that occupants will flee towards the exit where they entered, towards the closest exit, or towards a user-defined exit. This parameter will be assigned globally. Fifty percent of the people will head for the closest exit, while the other half will return to the familiar exit. If groups meet a blocked area, they will be re-routed towards the closest exit seen from that position.

### Emergency procedure modelling

The emergency exits at Schiphol are not locked, and can therefore be opened by the escaping people. There are no customs or security check areas in this pier. The handling times at the boarding check units will be set to zero when an evacuation starts. Occupants can flee through these zones without objection.

### Evacuation procedure modelling

An integral evacuation will be executed, which means that the pier will be cleared directly, not step-wise.

### Verification and validation

The input of the parameters has been checked, and different test runs have been executed to assess the validity of the model. Most part of the Schiphol model appeared to work properly. We would like to make two comments, though.

A surprising result was the fact that congestion appeared at the beginning of a conveyor. This shows, that groups use conveyers during emergencies, even though free space along the conveyor could be used. The shortest path algorithm causes an unrealistic situation. This type of problem should be solved in order to gain a representative evacuation simulation. A solution could be to calculate the shortest process time towards a destination, instead of the shortest path.

Another comment should be made on the movement of groups during evacuations. From the animation of the Schiphol model became clear that in some areas groups were fleeing in platoons. Analysing the flight behaviour in bridges, we saw that at the moment the emergency breaks out, the entire surface capacity of this area is directly claimed. This is an unrealistic situation, since there is a maximum number of persons that can enter an area at the same moment. We saw a platoon of groups, theoretically large enough to occupy the entire bridge, moving from the one side of the bridge to the other side. At the moment the groups arrived at the end of the bridge, a new platoon enters on the other side. Creating an object representing an internal doorway, which has been described before, has solved this problem.

From this second comment, we can conclude that the modelling of areas as resources has disadvantages. We should consider positioning a door at the beginning of an area, the use of smaller areas, or a grid-based terminal representation.

Due to the fact that solving these problems would be very time-consuming, we decided to continue with the experiments.

## *15.4 Scenario variations*

First of all, though, we will run two best case scenarios, in which there is no detection time, no pre-movement time, and no emergency growth, and in which all occupants flee towards the closest exit. In the first scenario occupants can flee through all exits, including the bridges, in the second the bridges will not be used as exit. This can be seen in Table 15-1.

In the created Schiphol emergency model, we could also make up more realistic scenarios to evacuate the terminal. For this study, we have decided to vary the scenario using two different parameters, namely:

- the use of the bridges as emergency exits;
- the growth of an emergency.

The use of bridges as emergency exits will lead to a larger exit capacity for the entire pier, so people might be more evenly divided over all exits, most probably leading to shorter waiting times and a shorter building evacuation time.

The emergency growth leads to less flight possibilities, and groups getting trapped in the building.

Combining these two parameters, we can define a matrix containing four scenarios, as can be seen in the last two columns of Table 15-1. With these four scenarios we will run the experiments.

*Table 15-1: Scenarios for the Schiphol F-pier experiments*

| | **Best Case** | **Emergency growth** | **No emergency growth** |
|---|---|---|---|
| **Bridges are exits** | Scenario 1 | Scenario 3 | Scenario 5 |
| **Bridges are no exits** | Scenario 2 | Scenario 4 | Scenario 6 |

## 15.5 *Running experiments*

Now we have defined model and the six scenarios, we can start running the experiments and interpreting the results.

### Expert expectations

We have asked some experts to predict the evacuation time of the terminal building before we ran the experiments. For these predictions, we have used scenario 1, in which occupants can use the bridges as emergency exits, and scenario 2, in which bridges are not used as exits. The expert predictions all lied between 6 and 10 minutes. A list of the experts and their expectations is provided in Appendix XV.

### Run Length

A run starts with an empty system, which will be filled with passengers. The end of a run is determined by the moment of evacuation of the last person. The system can be considered an ending system.

## Number of runs

In order to be able to see the variations caused by the changing stochastic values, we have run five different replications for each scenario. Based upon variance and standard deviation, we can determine the number of runs we should execute in order to gain a certain level of confidence. Since this case study was just a pilot study, and does not aim at obtaining realistic results and finding solution for Schiphol, we did not go into these matters very deeply. We only ran the different replications in order to show that the evacuation times could differ significantly, when other random values are used.

## Results

The results of the simulation runs are shown in Appendix XVI. We can see, that the evacuation times vary significantly. For the best case scenario in which the occupants can use all exits, an average total building evacuation time of 402 seconds (almost 7 minutes) is generated, whereas the best case scenario without use of bridges shows an evacuation time which is twice as long. The extra exit capacity leads to significantly shorter evacuation times.

As an example, a comparison between the results of the scenarios is shown graphically. For this representation, we have used the scenario with the median building evacuation time. The best case scenarios are shown in Figure 15-5.

The scenarios with a growing emergency (scenario 3 and 4, Figure 15-6) show shorter evacuation times than the scenarios without emergency effects (scenario 5 and 6). Firstly, this is caused by the fact that one fourth of the occupants gets trapped, and therefore do not use the exit capacity. Secondly, the pre-movement times of some of the occupants is shorter because groups interact with the emergency.

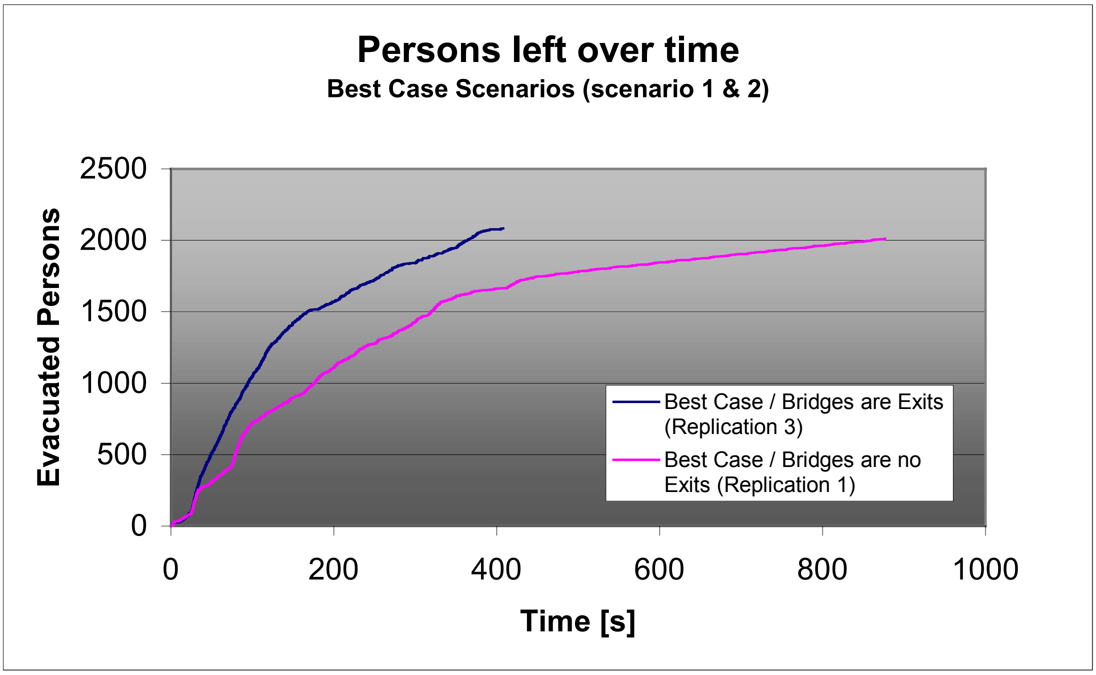


*Figure 15-5: Comparison of the number of evacuated persons over time for the two best case scenarios. In this graph, the scenarios with the median evacuation times have been used. The time scale starts at 0, which is the moment that the emergency breaks out.*

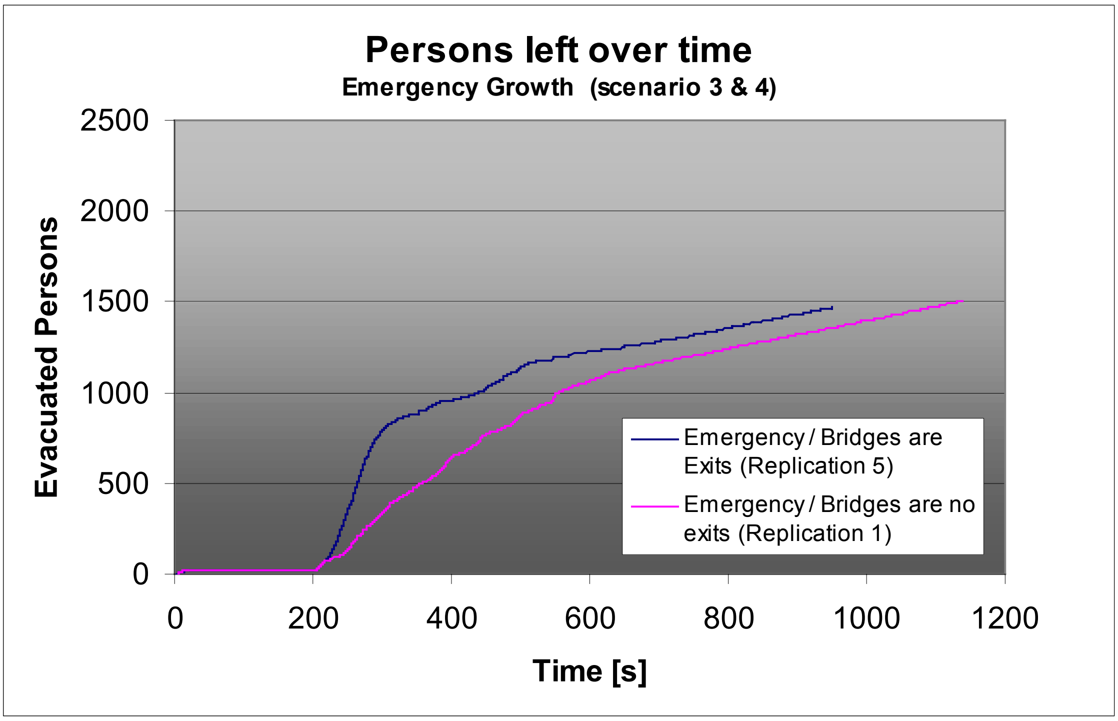


*Figure 15-6: Comparison of the number of evacuated persons over time for the two scenarios with emergency growth. In this graph, the scenarios with the median evacuation times have been used. The time scale starts at 0, which is the moment that the emergency breaks out.*

Concerning the other scenarios without emergency growth (scenario 5 and 6), as represented in Figure 15-7, we could say that the differences in building evacuation time are not that big. This is interesting, since the exit capacities differ significantly, as was shown in the previous scenario. The fact that half of the occupants flee through the large entrance at the foot of the pier, leads to less congestion.

In this figure we could see clearly that there is a detection time and a pre-movement time. Only after about 200 seconds the first person leaves the building. Remember that the detection time in the model was 180 seconds.

All scenarios show congestion near the staircases and the Boarding Unit Checks. This makes clear, that not only the statistics of the Emergency Exit itself are relevant, but also those of the possible bottleneck before the exit. Often the entrance of the escape route will be the most significant bottleneck. It is recommended to introduce a more graphic representation of the bottlenecks, such as a floor plan with a coloured projection of the maximum density or maximum waiting queues in the different areas.

When we compare the expert expectations for scenario to the model results, we can see that the model results approximate the expectations.  This does not mean, though, that the model is valid. Both expert predictions and model results could still be based upon wrong expectations. More validation steps are recommended, before the model is considered valid.

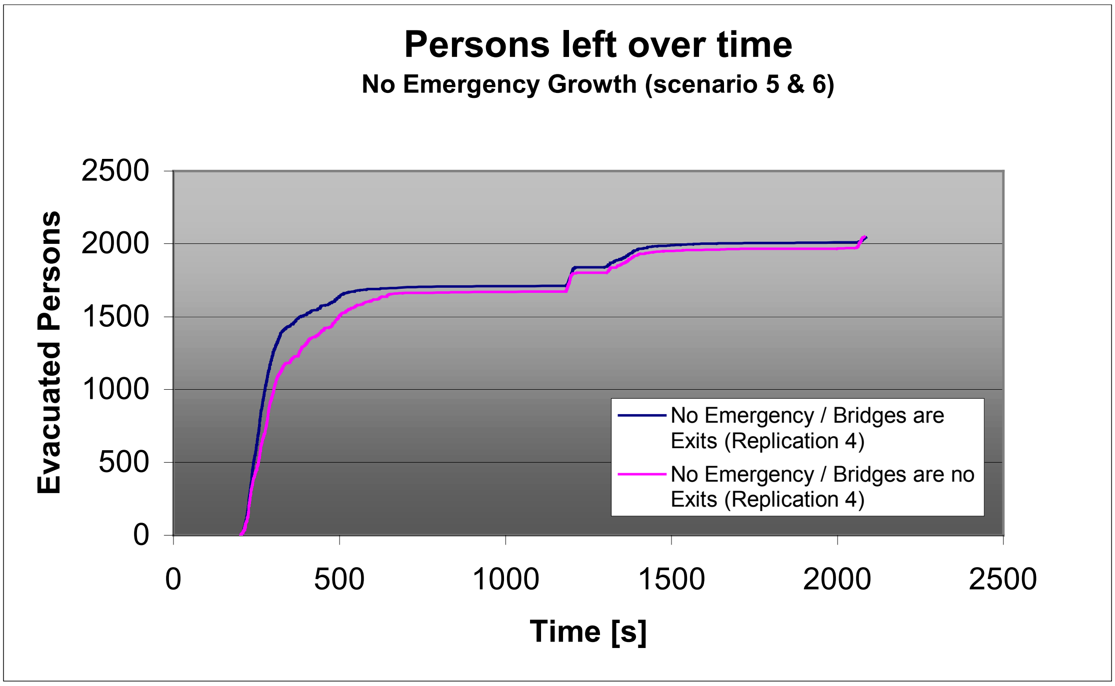


*Figure 15-7: Comparison of the number of evacuated persons over time for the two scenarios without emergency growth. In this graph, the scenarios with the median evacuation times have been used. The time scale starts at 0, which is the moment that the emergency breaks out.*

## 15.6 Conclusions

Some important conclusions can be drawn from the Schiphol case. In this paragraph we will mention the essential ones.

### The model works

After the Schiphol case and the Safe Town Airport case, we could conclude that the model conceptually works, also for terminals with a larger amount of objects and more groups. It is still hard to say whether the model is valid or not, although the expert predictions on the best-case scenarios were close to the model output.

It is recommended to try other validation methods to be able to assess the quality of this model. One of the possibilities could be to compare the model results to simulation results produced by other evacuation packages, such as Exodus or Simulex. Another possibility would be to gain quantitative data concerning real evacuations or evacuation exercises.

### Results depend highly on input

The results of the simulation runs depend highly on the chosen input parameters. The chosen pre-movement time distribution for example, is a factor that determines the total building evacuation time significantly. Before we design the scenarios to be run, it is relevant to define the objective of the study, and to see if this objective can be met using the designed scenarios. The modelling of random emergencies could lead to results we cannot interpret, since we cannot compare them to other figures.

### Detailed input required

Within this model, we tried to avoid black box modelling, which could be unclear to the user. This openness requires the user to determine a lot of parameters and distributions, such as pre-movement times, script assignments and specific flows through doors. This can cause complications during the modelling phase. The user should make up his mind about questions such as:

- In what way does the pre-movement time depend on the signage?
- In what way does the route choice depend on the presence of personnel?

In the introduction, we have described that it is an advantage to be able to simulate normal operations and evacuation scenarios in one and the same library. At the moment that no normal model is available and the objective is only to simulate evacuation, though, it is a rather extensive job to gather input data such as flight schedules and gate allocation. It is questioned, whether the output has a higher validity due to this detailed input and it would be less time-consuming to ‘throw’ a certain number of passengers randomly into the terminal.

### Some exits are not used at all

Watching the Exit Statistics Table, we notice that in some scenarios, some exits remain unused, although they seem to be attractive. At the moment, groups assess exits only on familiarity and distance towards the exit. But more characteristics are important. Some exits are more visible than others, or the signage indicating these exits is better. In the current model, all exits, no matter how hidden or badly indicated, are considered to be equal.

Another problem is the fact, that the distance towards an exit is considered, and not the distance towards an escape route. For the Schiphol model this suggests, that groups know how long the corridors and staircases are that lead towards the exit. It might be more realistic to consider the distance towards the start of the escape route.

A reconsideration of the exit choice is recommended. We might for example introduce weighing factors to include these important factors into the model.

### Over-crowded gate wait areas

Since the only objective of the departing passengers in the pier is to wait for their flight, they directly walk towards the wait areas. In this simulation, these areas where over-crowded. This might have had an effect on the results of the simulation runs, since it took groups a long time to leave this first area. In the future the simulation should be extended with arriving passengers, and other areas such as the restaurant area.

# PART V

# Evaluation, Conclusion and Recommendations

# 16 Evaluation

In this evaluation chapter, we will see if the built model meets the initially set requirements, and if the boundaries were properly defined. We will conclude this chapter with remarks on the research process during the last seven months, and suggestions how to improve this.

## 16.1 *Requirements*

In one of the first chapters we have defined the requirements the evacuation model would have to meet. In this paragraph, we will evaluate these requirements.

### Representative modelling

While modelling emergencies and evacuations, we have tried to stay as close to reality as possible, for example by offering the possibility to assign different evacuation scripts and pre-movement times. Nevertheless, as can be seen in one of the previous chapters, we had to make some assumptions and simplifications, either because it was hard to gain valuable information on some relevant issues, or because it would too much increase the level of complexity.

### Generic objects

The evacuation objects were supposed to be generic, so it would be possible to apply them to different airports, without changing the properties of the building blocks. In this research we showed that the same objects were easily applicable to both Safe Town Airport and Schiphol. We could therefore conclude that the objects are generic. Beside this, it is important that the models created with the Airport Passenger Library are relatively flexible. It is easy to adapt relevant values or to change the network.

In addition, it is possible to use the generic objects to create airport specific objects. In the Schiphol case we created the Escape Route object, which represents the combination of corridors, stairs and an emergency exit, as present in the F-pier.

### Comprehensible user interface

One of the objectives of the Airport Passenger Library is to make the process of airport simulation user friendly. While creating the new building blocks we have tried to create an understandable user interface, consisting of dialogs with user input. The advantage of this approach is that users can work on two levels, namely the level presented by the user interface, and the level of program code that lies beneath. Nevertheless, it should be mentioned that the user have to determine a lot of parameters himself. Working with emergency scenarios is not recommendable to people without knowledge of evacuations and simulation skills. Finally, we would like to emphasise that the Airport Passenger Library as a whole is not very accessible and understandable yet. We will come back to this later.

### Visualisation of the process

We have been capable of creating a visualisation on which we can see the occupants move through the building. This should be considered a means to make the processes understandable. There are some weaknesses, though.

One should realise that this animation is not completely representative for the process. It suggests that the exact position of the groups in the model is known, which is not true. Besides, group sizes are not displayed, since each group uses the same animation. Nevertheless, the given animation helps the user to understand the process, which is the major objective of animation. Experts can judge the behaviour without understanding the underlying programming code, which is the main objective of animation.

Besides, constructing the animation part of the Airport Passenger Library is very time-consuming, since the co-ordinates of the areas have to be manually determined. It is recommended to improve the animation possibilities of the library.

### Comprehensible simulation output

The output of the simulation has to be useful and clear. By creating the Evacuation Statistics object, we have collected the relevant output, so the user can easily interpret the results. It would be better to develop a way to present only the relevant information. When presenting the area statistics for example, we are mainly interested in the bottlenecks. It would be good to map the areas with long queue times and large densities graphically, for example by using different colours.

## *16.2 Boundary Conditions*

Because of the limited time available for this thesis, some boundaries were set to define the system. In this chapter we question what influence these boundary conditions have had on the result of the research.

### Focus on human behaviour and construction

Since this research focussed specifically on the factor of human behaviour and the impact of the construction, we have to be careful interpreting the results. The subject of emergency evacuation is so broad, that major simplifications have been made, not only concerning fire and smoke production and movement, but also concerning human behaviour and construction.

Emergency impact, though, could be taken into account using these emergency objects, but only in an indirect way. By means of a data preparation step we can translate sophisticated smoke and fire development scenarios into an Emergency Growth table and pre-movement time distributions. Nevertheless, the results of basic evacuations as they can be simulated right now, can be useful when we want to assess the safety of an airport terminal. In future, it will be possible to expand the evacuation model with dynamic smoke and fire models also concerning toxicity and visibility.

### Focus on microscopic models

The microscopic view considering each occupant individually can still be expanded, for example by dividing groups into individual group members, or by assigning more personal attributes. Whether this will have great influence on the results of the simulation runs, has to be explored later.

### The existing library is correct

The library is still under construction. The assumption that the existing library was correct, can therefore be considered a little too optimistic. At some stages, the existing building blocks had to be adapted. Furthermore, some features were still missing, such as a user-friendly animation function. Later in this report, we will give some suggestions for improvement of the library.

Some objects are created without taking the possibility into account that they could be used for evacuation and emergency purposes in future.

# 17 Conclusions and recommendations

In this chapter we will conclude this research on evacuation of airport terminals by comparing the results with the initial objective of the research. From April until December 2001 we have made a start with the development of an evacuation model within the existing Airport Passenger Library.

After presenting the conclusions so far, we will give some recommendations on how to proceed with this project. Furthermore, there will be some recommendations concerning the future development of the Airport Passenger Library in general.

## *17.1 Conclusions*

The purpose of this research was, to offer the possibility to model flight behaviour in airport terminals. Using this tool, it should be possible to assess safety in case of emergency.

### Modelling of evacuations possible

During this research we managed to implement building blocks that successfully describe evacuations in airport terminals. It is conceptually possible to model emergency growth within the terminal, to assign pre-movement times to occupants, to send occupants into different escape directions, et cetera.

The evacuation and emergency model is an abstraction of the real terminal. It could especially be useful to evaluate the safety of new terminal designs and terminal changes, giving a better overview of the bottlenecks within the terminal during evacuations, than existing calculations prescribed by legislation.

We must conclude, though, that modelling processes like this, is still a very complicated matter, with much insecurity. There are a lot of relevant parameters, and if we want to describe them all, including their interactions, we have to execute many scenarios. During this research we have tried to focus on the most relevant characteristics of areas, individuals and procedures. This means, that the model we have presented is still on a high level of abstraction, and still many features can be improved. This does not mean, that the results cannot be valid, though. We faced some problems during the quantitative validation, which could not be properly executed due to lack of proper data.

### Outcomes are relative

The success of evacuation models depends highly on the way the output is interpreted. An absolute evacuation time does not give any relevant information if we do not mention the values of the input parameters. Beside this, it is recommended to use this simulation tool as a relative tool, with which different scenarios can be compared. Until the model is thoroughly quantitatively validated, only the conclusion 'A is better than B' is justified, and not for example the conclusion 'The evacuation of the people in the terminal takes about 4 minutes'.

### High level of abstraction

Using this model, evacuation cannot be modelled very precisely, since the level of detail is still relatively small. Areas are modelled as black boxes, not as spaces with objects and obstacles. It is for instance not clear if a person is situated in the northern corner of the room, or in the southern corner, though there might be some twenty metres between these positions. Besides, problems can occur with counter flows. The fact that flows could come from different directions is not taken into account, though occupants might hinder each other.

By comparing the model to realistic data or outcomes of other evacuation software, we should try to find out, whether the chosen level of abstraction is the right one, or we should describe the movement of occupants in more detail.

## 17.2 Recommendations

Since the Airport Passenger Library is still under development, further research will have to be done. In this paragraph we will recommend some of the possible directions in which this research could go. Hereby we will present recommendations concerning future expansion and improvement of the evacuation model. The suggestions with regard the development of the library as a whole, are presented in Appendix XVII.

### Explore the advantages of a tighter grid

The most important question that remains unanswered is, whether it would be better to use a tighter grid or not. This will provide the occupants with a more exact position within the terminal, and it will enable them for example to overtake slower occupants. Beside this, the modelling of the areas around doorways can be more specific, including the crushing and pushing of crowds.

Before continuing with the development of the evacuation features, though, it would be interesting to analyse the advantages of using a multi-grid, with small tiles (for example 0.5 by 0.5 meters) on which the occupants move. For answering this question we will have to be able to assess the validity of the current model, and see whether this model meets the demands. In other words: before we increase the level of detail, we will have to prove that the existing model does not meet the requirements. Increasing the level of detail, namely, will lead to longer processing time of the simulation and a more detailed and time-consuming input. To analyse the effect of using smaller areas, we could start to create a more detailed model using the existing library.

### Introduce hazard model

It would be useful to extend the model with hazard models, describing the growth and implications of emergencies on human behaviour. For modelling cases of fire, for example, we could think of implementing smoke and fire production sub-models, or link the emergency growth list to software that calculates these effects. This way, growth scenarios will be more realistic, and also the effects of smoke and fire on the individual can be taken into account. These effects will have a significant influence on the movement of individuals, and therefore on the evacuation process. However, we should not only focus on fire and smoke, but also on the other emergencies we mentioned in chapter 4.

### Extend the object library

With the objects within the library we could not simulate all aspects of the terminal. At the moment, there are for example no building blocks to simulate toilets, restaurant areas, staircases, escalators, revolving doors, and sliding doors. Some of these, especially the staircases, play a significant role during evacuation scenarios.

Next to the extension of the public zone, we could consider extending the model with non-public zones, such as offices. At Schiphol Airport for example, many office buildings will be evacuated through the terminal building. This will create a large amount of new terminal occupants.

### Improve existing objects

As we concluded after the Schiphol case, some of the existing objects describing emergency and evacuation have to be improved, and new features could be implemented.

In the existing model, all groups take the shortest route towards their destination. During the evacuation of the Schiphol model we have seen that this could lead to strange situations, when all evacuating groups tended to use the conveyors, while the walking area along the conveyors remained empty. We should consider developing a more advanced algorithm that takes into account not only the distance, but also the density of certain routes.

The introduction of luggage and luggage trolleys will have a significant impact on the behaviour of occupants. It will decrease the walking speed while it will increase the surface used. Besides, not all areas are accessible to trolleys. Leaving them behind near entrances might obstruct other people in their escape. Luggage and luggage trolleys can be easily implemented by differentiating occupant behaviour by means of introducing new scripts, and by changing the group attributes walking speed and surface used.

Beside this, groups are normally influenced by other groups. They might for example inform each other during the flight, either by giving direct information, or by simply showing the direction in which they are fleeing by fleeing itself. In the current model, local pre-movement times represent the local communication. This is an indirect way of representing such an influence. Groups do not really communicate. The concept of groups warning other groups with a different script that an area or exit is closed, is not taken into account at all.

Concerning the statistics and animation, we could conclude that it is recommendable to improve the representation. A more graphical representation, showing maps of the terminal with coloured bottlenecks, would decrease the time spent on the interpreting of the output.

### Improve interface to CAD

The model construction phase is rather extensive in the current model. It would be good to explore the possibilities of linking the simulation tool to Computer Aided Design (CAD) tools such as AutoCAD, as used by architects. This way, the translation of the architectural design into a simulation model can be improved, storing the information useful to both spatial design and simulation in a central database. The iterative change of the design after conclusions of a simulation study can be accelerated. Beside this, the animation can be simplified using the co-ordinates from the CAD.

### Gain quantitative data

In order to validate the model properly, it is necessary to explore the possibilities to gain more quantitative data to validate this model. Accident research is a very important means to enlarge the safety of our built environment.

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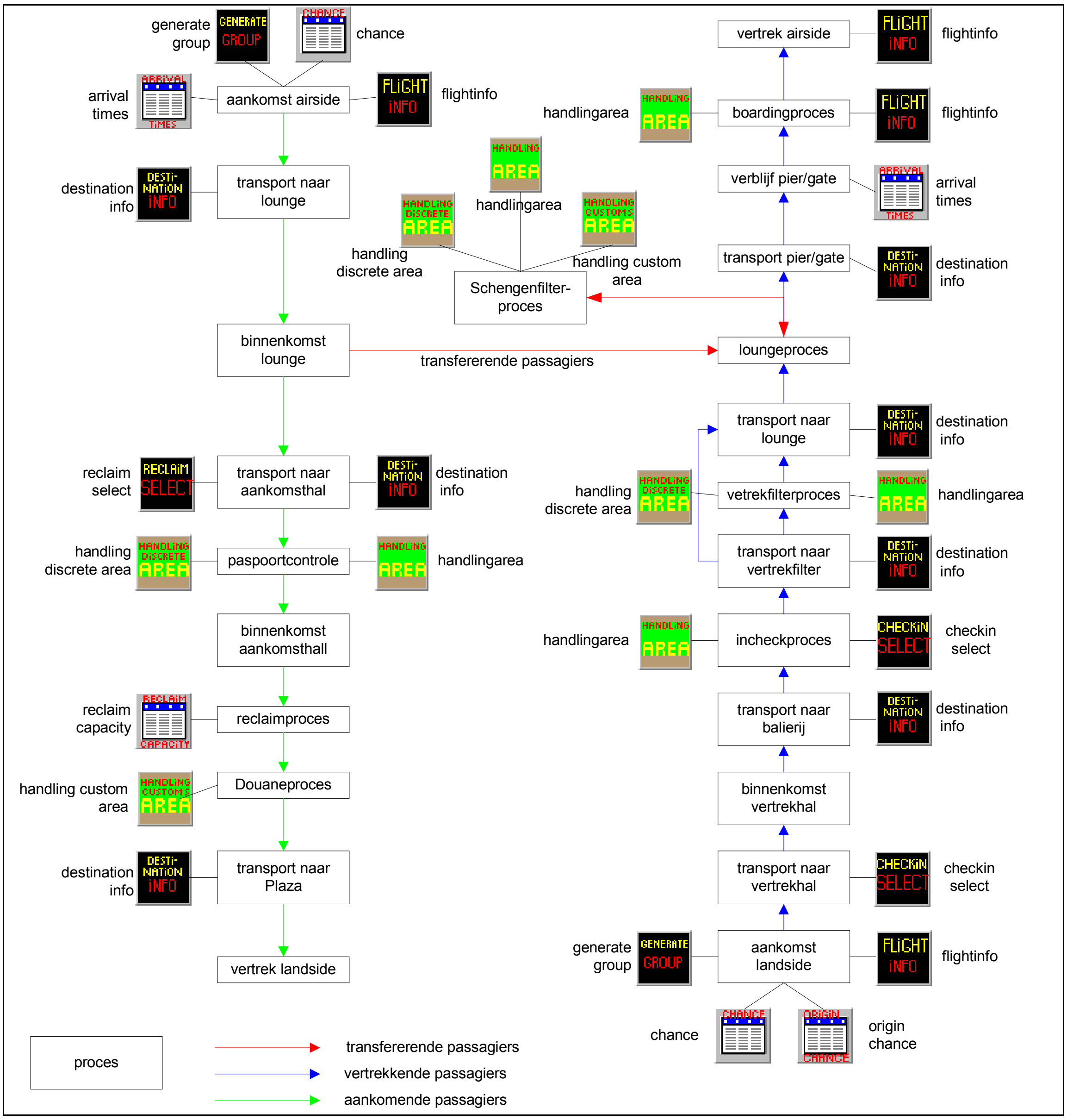
# Appendix I Process Model Passenger

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## Appendix II Translation Literature Research Conclusions into Implementation

| *Airport Terminals: Building Characteristics* | |
|---|---|
| **Conclusion** | **Implementation** |
| The behaviour performed in case of emergency depends highly the physical location and properties of the area, and on the current activity performed within the area. | Pre-movement time and evacuation script can be assigned locally. |
| Especially the waiting queues generated at some locations might cause increased pre-movement times. It is important to see that queuing people are not eager to leave behind their position, because they have been standing there for a long time already. | Longer pre-movement times can be assigned to those in queues. |
| During an emergency, areas that are generally not accessible, such as the apron, or only accessible after a certain procedure, such as a passport check, might be a barrier to some occupants, which causes the time to escape to increase. | Attractiveness of exits is not taken into account in this model. The distance towards exit is the only criterion taken into account. |
| Activities in amusement arcades and at public telephones are especially distractible to people in a way that leads them to pay less attention to the environment. | Longer pre-movement times can be assigned to those in amusement arcades and public telephones. |
| Another area with high risk is the restaurant area, since the equipment used in these areas is more likely to cause fire, and the bystanders in these areas are less alert to smoke. | Longer pre-movement times can be assigned to those in restaurants. |
| In the retail area, the commitment of personnel to the activity they perform might be high. The closing of shops or the gathering of valuables might slow down the evacuation of personnel. | Personnel have not been modelled yet. |
| Terminal layout has an influence on the possible emergencies and the respective evacuations. The presence of underground pedestrian routes and the density of people are important factors. | |

| *Airport terminals during emergencies* | |
|---|---|
| **Conclusion** | **Implementation** |
| Care has to be taken when power-actuated swinging and sliding doors, or elevators are used, since they might not function during a power failure. | Scenarios with malfunctioning objects can be designed and executed. |
| Crushing can occur in areas where many people are concentrated and limited emergency egress is available. The crushing might even be stimulated by luggage or luggage trolleys, blocking the exits. | Luggage and luggage trolleys have not been modelled. Blockages of exits, though, can be modelled. |
| Terminal buildings are generally full of signs, varying from signs with texts to pictograms. In case of emergency, this might cause 'competition' between the normal signs and the emergency signs, resulting in a situation in which people oversee the egress signage. | Signage is hard to quantify. It can be taken into account when modelling the pre-movement time scenarios. |
| Within most airport terminals, a good public address system is available. The availability of public address system, though, does not mean that it can always be used, or that it is always used properly. | The effect of cues and more specifically the public address can be taken into account when modelling the pre-movement time and script assignment scenarios. |
| Initial cues are generally not provided by the public address system, but by the emergency itself. In large buildings such as terminals, these cues are available to a small part of the population. The problem is that people tend to neglect these cues. | People meeting the emergency will directly get assigned a new script according to the ReassignedEvac-Script method. |

| *Airport terminals: occupants and behaviour* | |
|---|---|
| **Conclusion** | **Implementation** |
| Within airport terminals many different occupants can be distinguished. We can see two different categories of terminal users: the actors offering services, such as airline personnel and shopkeepers, and those using these services, such as passengers. | At the moment, only passengers are modelled. The effect of personnel on the behaviour can be introduced in scenarios. |
| It is crucially important to examine the nature of behaviour in normal circumstances and therefore during the early stages of an emergency when most time is lost. | The effect of area characteristics on the behaviour can be introduced in pre-movement time and script assignment scenarios. |
| Airline passengers can be subdivided according to different characteristics, such as leisure or business travellers, charter or scheduled flight passengers, et cetera. The different categories show different behaviour within the terminal. | Different passengers can be introduced using the Group Generator and different chance tables. Group size, normal script and walking speeds are important. |
| Problems during evacuation can be caused by heavy luggage, disabilities, and commitment to their current activity, such as having a meal in a restaurant or lining up for check in. | Luggage and disabilities can be included in the walking speed distribution, commitment in the pre-movement time distributions. |
| The airport police, security personnel and customs are trained to deal with uncommon situations, including emergencies. Their role during evacuation will be to direct occupants safely out of the building and to control the emergency. | Emergency resources have not been modelled yet. The effects of possible directions might be included in the pre-movement time and script assignment distributions. |
| In case of fire, the fire departments will be alerted. Their tasks will be to fight the fire and to secure the safety of the occupants of the building. They can direct occupants out of the building or inform other emergency resources to do so. | Firemen have not been modelled yet. The effects of possible directions might be included in the pre-movement time and script assignment distributions. |
| Although airline personnel usually do not have responsibilities within the terminal, training and education might influence the way they act during emergencies in the terminal. | Airline personnel have not been modelled yet. The effects of possible directions might be included in the pre-movement time and script assignment distributions. |
| If in-house emergency and first-aid service personnel are able to guide people to the nearest emergency exit, long walking distances can be avoided. | These personnel have not been modelled yet. The effects of possible directions might be included in the pre-movement time and script assignment distributions. |
| During emergencies, criminals and homeless people be interested in the belongings of others instead of their own safety. Homeless people might show a slower reaction because of the use of alcoholic beverages. | Criminals and homeless people have not been modelled. |

| *Emergency behaviour in airport terminals* | |
|---|---|
| **Conclusion** | **Implementation** |
| The pre-fire activity consists of one of the activities performed within airport terminals, such as buying tickets, checking in, waiting for departure, et cetera. | Pre-emergency activities are included in the existing Airport Passenger Library, though some functions such as restaurants and toilets fail. |
| The cue reception phase in airport terminals is characterised by direct interaction of the occupants and the emergency, alarms and alarm systems, public address systems with spoken messages, or by social communications between people that warn each other. | Direct interaction is included. After a detection time occupants start to evacuate. Social interactions are not modelled, apart from the fact that people in the same area get assigned a pre-movement time according to the same distribution. The react more or less at the same moment. |
| As only a very small percentage of airport occupants will be at the exact location of the emergency, close enough to try to avoid growth, and feel himself responsible to do so, passengers are presumed not to perform fire fighting activities. | No fire fighting actions are taken into account. They might be included in the emergency growth scenario, though. |
| The emergency fighting action is just performed by the emergency resources fire department and police. In-house emergency and first-aid service people, security personnel and customs might assist these resources in warning people, while the others evacuate. | No emergency resources have been modelled. |
| Most of the normal occupants, such as passengers, personnel, meeters and greeters, et cetera, will leave the building as soon as they notice an emergency. | In the Airport Passenger Library all passengers evacuate when an emergency breaks out. |
| Specifically within airport terminals, individual characteristics such as physical disabilities, number of luggage pieces, training, experience and education, language skills, affiliation, commitment to activity, are of importance. | The population has three parameters during emergency scenarios, namely pre-movement time, a destination in an evacuation script and a walking speed. Most of the other parameters have influence on these three main parameters, as is shown in Appendix VIII to Appendix X. |
| Social influences and group behaviour within airport terminals must not be underestimated. | Groups that travel together stay together during evacuation. Groups cannot communicate with each other in the current model. |
| A very important characteristic of airport terminals is the large amount of staff present, which might cause different evacuation scenarios than with less staff, since people can be more easily guided. | Influence of staff on behaviour can be included in the scenarios, varying pre-movement times and script assignment distributions. |

## Appendix III Emergency and Evacuation Object Model

| EMERGENCYCONTROL | | |
|---|---|---|
| **General description:** | **Controls the emergency growth and initiates the EvacuationControl** | |
| EmergencyOn :boolean | **Description:**<br>**Read by:**<br>**Written by:** | tells whether an emergency scenario is to be executed or not<br>EMERGENCYMETHOD<br>USER |
| StartEmergency : time | **Description:**<br>**Read by:**<br>**Written by:** | moment that the emergency breaks out<br>INIT, EMERGENCYMETHOD, EVACSTATS.ADDEVACSTATS<br>USER |
| DetectionTime : time | **Description:**<br>**Read by:**<br><br>**Written by:** | time between the start and the detection of the emergency<br>EMERGENCYMETHOD, AREAEVACCONTROL.ASSIGNPREMOVTIME, EVACSTATS.ADDEVACSTATS<br>USER |
| GrowingEmergency :boolean | **Description:**<br>**Read by:**<br>**Written by:** | tells whether an emergency is growing, i.e. whether areas will get blocked<br>EMERGENCYMETHOD, EVACSTATS.ADDEVACSTATS<br>USER |
| Status :string | **Description:**<br><br>**Read by:**<br>**Written by:** | tells whether there is still normal operation, or the emergency has started already<br>--<br>EMERGENCYMETHOD, RESET |
| InitResistance :boolean | **Description:**<br>**Read by:**<br>**Written by:** | tells emergency growth has changed resistance or not<br>RESET<br>EMERGENCYGROWTH, RESET |
| InitHandlingDistr :boolean | **Description:**<br>**Read by:**<br>**Written by:** | tells emergency growth has changed handling times or not<br>RESET<br>EMERGENCYMETHOD, RESET |
| GrowthCount :integer | **Description:**<br>**Read by:**<br>**Written by:** | counts how many areas have been blocked since the emergency started<br>AREAEVACCONTROL.REASSIGNEVACSCRIPT<br>AREAEMERGENCYCONTROL.BLOCKAREA, RESET |
| RecalculateCount :integer | **Description:**<br><br>**Read by:**<br>**Written by:** | counts if shortest path has been calculated after emergency growth has taken place<br>AREAEVACCONTROL.REASSIGNEVACSCRIPT<br>AREAEVACCONTROL.REASSIGNEVACSCRIPT, RESET |
| Init<br>() | **Description:**<br>**Called by:**<br>**Calls:** | initiates emergency<br>EVENTCONTROLLER<br>EMERGENCYMETHOD |
| EmergencyMethod<br>() | **Description:**<br>**Called by:**<br>**Calls:** | initiates emergency growth, and initiates evacuation<br>INIT<br>EMERGENCYGROWTH, ROOT.MISSIONCONTROL.EVACUATIONMETHOD, CALLEVERY(ENDWARMUPTIME), CALLEVERY(SETEMERGENCYHANDLDISTR), |
| EmergencyGrowth<br>() | **Description:**<br><br>**Called by:**<br>**Calls:** | reads EmergGrowthTable and call method within the areas named in this table in order to increase its resistance<br>EMERGENCYMETHOD<br>SINGLEAREA.AREAEMERGENCYCONTROL.BLOCKAREA |
| Reset<br>() | **Description:**<br>**Called by:**<br>**Calls:** | sets status to normal operation<br>EVENTCONTROLLER<br>~.AREADIRECTION.GENERATESHORTESTPATH, CALLEVERY(DEBLOCKAREA), CALLEVERFY(RETURNINITHANDLDISTR) |
| **INCLUDED OBJECT – EMERGGROWTHTABLE** | | |
| General description:Describes the growth of the emergency | | |
| **INCLUDED OBJECT – DIALOGFRAME** | | |
| General description: Dialog frame specialized for EmergencyControl | | |

## EvacControl

| General description: | Controls the evacuation of groups out of the building | |
|---|---|---|
| EvacuationOn :boolean | **Description:**<br>**Read by:**<br>**Written by:** | tells whether an evacuation is to be executed or not<br>EvacuationMethod<br>User |
| LocalGlobalScript :string | **Description:**<br><br>**Read by:**<br>**Written by:** | tells whether script assignment is done according to local or global distribution, i.e. each area a different distribution or not<br>AreaEvacControl.AssignEvacScript, EvacStats.AddEvacStats<br>User |
| LocalGlobalPreMov :string | **Description:**<br><br>**Read by:**<br>**Written by:** | tells whether pre-movement time assignment is done according to local or global distribution, i.e. each area a different distribution or not<br>AreaEvacControl.AssignPreMovTime, EvacStats.AddEvacStats<br>User |
| GlobalPreMovTime :string | **Description:**<br><br>**Read by:**<br>**Written by:** | the pre-movement time for the entire model, used if global pre-movement time assignments should be given<br>AreaEvacControl.AssignPreMovTime, EvacStats.AddEvacStats<br>User |
| ReassignedEvacScript :string | **Description:**<br><br>**Read by:**<br>**Written by:** | name of the evacuation script that will be assigned in case a group meets a blocked area during evacuation<br>AreaEvacControl.ReassignEvacScript<br>User |
| MaxNoOfReroutings :integer | **Description:**<br><br>**Read by:**<br>**Written by:** | determines how many times a group will be reroute, before it is considered to be trapped by the emergency<br>AreaEvacControl.ReassignEvacScript<br>User |
| UseOfAreaReduction :real | **Description:**<br><br><br>**Read by:**<br>**Written by:** | sets the emergency reduction of the UseOfArea attribute of groups; as a consequence, more groups fit into a surface capacity area during emergencies.<br>EvacuateGroups<br>User |
| Status :string | **Description:**<br><br>**Read by:**<br>**Written by:** | tells whether there is still normal operation, or the evacuation has started already<br>--<br>EvacuationMethod, Reset |
| PersonsTrapped :integer | **Description:**<br>**Read by:**<br>**Written by:** | counts the number of persons trapped due to the emergency in the building<br>EvacStats.AddEvacStats<br>AreaEvacControl.GroupTrapped, Reset |
| FirstPersonEvacuated :real | **Description:**<br>**Read by:**<br>**Written by:** | registers the time of the first person evacuated<br>EvacStats.AddEvacStats<br>LeaveSystem.EvacStats, Reset |
| LastPersonEvacuated :real | **Description:**<br>**Read by:**<br>**Written by:** | registers the time of the last person evacuated<br>EvacStats.AddEvacStats<br>LeaveSystem.EvacStats, Reset |
| TotalEvacTime : real | **Description:**<br><br>**Read by:**<br>**Written by:** | registers the total building evacuation time, which is the interval between the onset of the cue and the last person evacuated<br>EvacStats.AddEvacStats<br>LeaveSystem.EvacStats, Reset |
| PersOutsideBuilding : integer | **Description:**<br><br><br>**Read by:**<br>**Written by:** | registers the number of persons that are located outside the building when the emergency breaks out; they will not be evacuated, since they are already in a safe area.<br>EvacStats.AddEvacStats<br>AreaEvacControl.EvacuateGroups, Reset |
| LeftBeforeOutbreak : integer | **Description:**<br><br>**Read by:**<br>**Written by:** | registers the number of persons that left in a normal way, e.g. by taking a scheduled flight; they left the system before the emergency broke out<br>EvacStats.AddEvacStats<br>LeaveSystem.ScriptMethod, Reset |
| PersonsEvacuated : integer | **Description:**<br><br>**Read by:**<br>**Written by:** | registers the number of persons that have been evacuated, i.e. left the system after the emergency broke out.<br>EvacStats.AddEvacStats<br>LeaveSystem.EvacStats, AreaEvacControl.EvacuateGroups, Reset |
| EvacuationMethod<br>() | **Description:**<br>**Called by:**<br>**Calls:** | stop creation of groups, delete statistics, remove groups from queues<br>EmergencyControl<br>AssignAreaAttr, CallEvery(EvacuateGroups), CallEvery(EndWarmUpTime), CallEvery(EmptyQueues) |
| AssignAreaAttr<br>() | **Description:**<br><br>**Called by:**<br>**Calls:** | assigns evacuation-related attributes to areas, such as local pre-movement times (method not in use yet)<br>EvacuationMethod<br>-- |
| Reset<br>() | **Description:**<br>**Called by:**<br>**Calls:** | sets status to normal operation<br>EventController<br>-- |

<table>
<tr><td>FillAreaTable<br>()</td><td>Description:<br>Called by:<br>Calls:</td><td>method used by the user to fill the area table with all the areas in the system<br>USER<br>--</td></tr>
<tr><td colspan="3">INCLUDED OBJECT – AREATABLE<br><br>General description:Table in which the area specific pre-movement times or pre-movement time distributions are listed</td></tr>
<tr><td colspan="3">INCLUDED OBJECT – SCRIPTASSIGNTABLE<br><br>General description:Table in which the global script assignment distribution is registered. distributions are listed</td></tr>
<tr><td colspan="3">INCLUDED OBJECT – EXITTABLE<br><br>General description:Table in which all exits in the model are listed.</td></tr>
<tr><td colspan="3">INCLUDED OBJECT – STATS (INSTANTIATED FROM GROUPSTATS (INHERITED FROM STATS))<br><br>General description:Stats of a group</td></tr>
<tr><td colspan="3">INCLUDED OBJECT – EMERGENCYDIALOG (INHERITED FROM DIALOGFRAME)<br><br>General description: Dialog frame specialized for EvacuationControl</td></tr>
</table>

| **EMERGENCYEXIT** (inherited from HANDLINGAREA (inherited from SingleAREA)) | |
|---|---|
| **General description:** | **Area representing an (emergency) exit or doorway** |
| DoorWidth :real | **Description:** width of the doorway<br>**Read by:** DETERMINEACTIONTIME<br>**Written by:** USER |
| WidthPerPerson :real | **Description:** width per person when passing the door<br>**Read by:** DETERMINEACTIONTIME<br>**Written by:** USER |
| SpecificFlow :real | **Description:** number of persons passing the door per meter per second<br>**Read by:** DETERMINEACTIONTIME<br>**Written by:** USER |
| AreaCapacity :real | **Description:** the number of persons that can pass the doorway at the same time<br>**Read by:** DETERMINEACTIONTIME<br>**Written by:** DETERMINEACTIONTIME |
| AreaCapacity :real | **Inherited from SINGLEAREA** |
| GroupInArea :list(object) | **Inherited from SINGLEAREA** |
| NrPersonInArea :real | **Inherited from SINGLEAREA** |
| ObjectOpened :boolean | **Inherited from SINGLEAREA** |
| Resistance :real | **Inherited from SINGLEAREA** |
| TypeOfCapacity :string | **Inherited from SINGLEAREA** |
| UsedCapacity :real | **Inherited from SINGLEAREA** |
| WaitingList :table (group) | **Inherited from SINGLEAREA** |
| Init () | **Description:** adds this exit to the ExitTable in the EvacuationControl object<br>**Called by:** EVENTCONTROLLER<br>**Calls:** -- |
| AddToNextAreaTable () | **Inherited from SINGLEAREA** |
| CheckGroups Waiting () | **Inherited from SINGLEAREA** |
| Reset () | **Inherited from SINGLEAREA** |
| DetermineActionTime (groupobj) :real | **Description:** Determines how long the activity will take for the group, depending on the door width, the width per person, and the specific flow.<br>**Called by:** AREA.ONARRIVE<br>**Calls:** -- |
| DetermineActionTime (groupobj) :real | **Description:** Calls the method "DetermineActionTime" of the object HANDLINGAREA.HANDLINGTIMETYPE<br>**Called by:** AREA.OnArrive<br>**Calls:** HANDLINGAREA.HANDLINGTIMETYPE. DETERMINEACTIONTIME |
| EndActivity (groupobj) | **Inherited from SINGLEAREA** |
| ExportData () | **Inherited from SINGLEAREA** |
| Init () | **Inherited from SINGLEAREA** |
| OnArrive (groupobj) | **Inherited from SINGLEAREA** |
| OnDepart (groupobj) | **Inherited from SINGLEAREA** |
| PlausibilityCheck ():bool. | **Inherited from SINGLEAREA** |
| Request (groupobj) | **Inherited from SINGLEAREA** |
| SetFamiliarExit (groupobj) | **Description:** if group enters the model, this doorway is the used entrance, if group leaves building, this is the used exit<br>**Called by:** AREA.ONARRIVE<br>**Calls:** -- |
| **INCLUDED OBJECT – STATS (INSTANTIATED FROM AREASTATS (INHERITED FROM STATS))** | |
| General description: | Stats specified for the Area, e.g. the number of persons within the area |
| **INCLUDED OBJECT – AREAANIMATION (INSTANTIATED FROM SINGLEAREAANIMATION)** | |
| General description: | Object for animation of the single area. |
| **INCLUDED OBJECT – DIALOGFRAME (INSTANTIATED FROM HANDLINGAREADF (INHERITED FROM DIALOGFRAME))** | |
| General description: | Dialog frame specialized for animation |
| **INCLUDED OBJECT – CAPACITYCONTROL (INSTANTIATED FROM CAPACITYCONTROLCONSTANT)** | |
| General description: | Control mechanism for determination of the capacity of the area, in the current class object the capacity is constant |
| **INCLUDED OBJECT – HANDLINGTIMETYPE (INSTANTIATED FROM HANDLINGTIMETYPE)** | |
| General description: | Determination of the activity time for a group within an area,depending on one distribution |
| **INCLUDED OBJECT – AREAEMERGENCYCONTROL** | |
| General description: | Control mechanism the local impact of a possible emergency |
| **INCLUDED OBJECT – AREAEVACUATIONCONTROL** | |
| General description: | Control mechanism the local impact of a possible emergency |

| AREAEMERGENCYCONTROL | | |
|---|---|---|
| **General description:** | **Controls the blocking of an area** | |
| InitialResistance :real | **Description:** | the initial resistance, representing the walking distance within an area, is stored here when resistance is temporarily increased due to emergency |
| | **Read by:** | RESET |
| | **Written by:** | SETEMERGENCYRESISTANCE |
| AreaBlocked :boolean | **Description:** | tells if area is blocked by emergency |
| | **Read by:** | SINGLEAREA.REQUEST |
| | **Written by:** | BLOCKAREA, DEBLOCKAREA |
| NormalIcon :string | **Description:** | the initial icon is stored here when the icon is temporarily changed into an emergency icon |
| | **Read by:** | -- |
| | **Written by:** | BLOCKAREA, DEBLOCKAREA |
| InitialHandlingDistr :real | **Description:** | the initial handling distribution is stored here when the handling time is temporarily increased due to emergency |
| | **Read by:** | RETURNINITHANDLDISTR |
| | **Written by:** | SETEMERGHANDLDISTR, RETURNINITHANDLDISTR |
| BlockArea (EmergResistance) | **Description:** | stores normal resistance in attribute InitialResistance, and changes Resistance into an emergency value; blocks area; deletes groups from waitinglist and reassigns them an evacuation script. |
| | **Called by:** | EMERGENCYCONTROL.EMERGENCYGROWTH |
| | **Calls:** | REASSIGNEVACSCRIPT |
| EmptyQueues () | **Description:** | Checks at the beginning of an emergency of the groups waiting in the queue to enter this area are really willing to enter this area. |
| | **Called by:** | MISSIONCONTROL.EVACCONTROL.EVACUATIONMETHOD, BLOCKAREA |
| | **Calls:** | -- |
| DeblockArea () | **Description:** | reassigns the initial resistance to the attribute Resistance |
| | **Called by:** | EMERGENCYCONTROL.RESET |
| | **Calls:** | -- |
| SetEmergHandlDistr () | **Description:** | stores normal handling distribution in attribute InitialHandlingDistr, and changes HandlingDistribution into an emergency value |
| | **Called by:** | EMERGENCYCONTROL.EMERGENCYMETHOD |
| | **Calls:** | -- |
| ReturnInitHandlDistr () | **Description:** | reassigns the initial handling distribution to the attribute HandlingDistribution |
| | **Called by:** | EMERGENCYCONTROL.RESET |
| | **Calls:** | -- |
| **INCLUDED OBJECT – INITHANDLDISTRTABLE** | | |
| General description:Table in which initial handling distribution table is saved. | | |

| AREAEVACUATIONCONTROL | | |
|---|---|---|
| **General description:** | **Controls the evacuation of groups within an area** | |
| AreaPreMovTime :string | **Description:** | the pre-movement time specific for this area, used if local pre-movement time assignments should be given |
| | **Read by:** | ASSIGNPREMOVTIME |
| | **Written by:** | USER |
| EvacuateGroups () | **Description:** | makes a list with the groups currently in the area and evacuates them |
| | **Called by:** | EVACUATIONMETHOD |
| | **Calls:** | ASSIGNPREMOVTIME, ASSIGNEVACSCRIPT |
| AssignPreMovTime (groupobj) | **Description:** | assigns a group an individual pre-movement time, based upon current area characteristics and group attributes |
| | **Called by:** | EVACUATEGROUPS |
| | **Calls:** | -- |
| AssignEvacScript (groupobj) | **Description:** | assigns a group an evacuation script, according to personal characteristics of the group and area characteristics |
| | **Called by:** | EVACUATEGROUPS |
| | **Calls:** | GROUPCONTROL.SCRIPTINTERPRETER |
| ReassignEvacScript (groupobj) | **Description:** | assigns a group a new evacuation script, when it starts to enter a blocked area |
| | **Called by:** | SINGLEAREA.REQUEST |
| | **Calls:** | GROUPCONTROL.SCRIPTINTERPRETER |
| GroupTrapped (groupobj) | **Description:** | assigns a group a new evacuation script, when it starts to enter a blocked area |
| | **Called by:** | SINGLEAREA.REQUEST, REASSIGNEVACSCRIPT |
| | **Calls:** | GROUPCONTROL.SCRIPTINTERPRETER |
| **INCLUDED OBJECT – SCRIPTASSIGNTABLE** | | |
| General description:Table in which the local distribution of scripts is set. | | |

| EvacStats | |
|---|---|
| **General description:** | **Collects the statistics, relevant to emergencies** |
| AddExitStats (Areaname, NrGroups, FirstIn, LastIn, AveQueTime, MaxQueTime, AveQueLength, MaxQueLength) | **Description:** Adds statistics concerning the exits in the model to a table.<br>**Called by:** EndSim<br>**Calls:** -- |
| AddDoorwayStats (Areaname, NrGroups, FirstIn, LastIn, AveQueTime, MaxQueTime, AveQueLength, MaxQueLength) | **Description:** Adds statistics concerning the doorways in the model to a table.<br>**Called by:** EndSim<br>**Calls:** -- |
| AddEvacStats () | **Description:** Adds statistics concerning the entire evacuation to a table.<br>**Called by:** EndSim<br>**Calls:** -- |
| AddAreaStats (Areaname, NrGroups, FirstIn, LastIn, AveQueTime, MaxQueTime, AveQueLength, MaxQueLength) | **Description:** Adds statistics concerning the areas in the model to a table.<br>**Called by:** EndSim<br>**Calls:** -- |
| EndSim () | **Description:** Starts collection of statistics when simulation run ended.<br>**Called by:** EventController<br>**Calls:** CallEvery(EndSimExitStats), CallEvery(EndSimDoorway-Stats), CallEvery(EndsimAreaStats), AddEvacStats, Save-EvacStats |
| Reset () | **Description:** Deletes the contents of the tables in this frame.<br>**Called by:** EventController<br>**Calls:** -- |
| SaveEvacStats () | **Description:** Saves tables to file.<br>**Called by:** EndSim<br>**Calls:** .Airport.Generic.Basic.SaveTableToFile |
| **Included object – ExitStatsTable** | |
| General description: | Table in which exit stats are collected. |
| **Included object – DoorwayStatsTable** | |
| General description: | Table in which doorway stats are collected. |
| **Included object – EvacStatsTable** | |
| General description: | Table in which evacuation stats are collected. |
| **Included object – AreaStatsTable** | |
| General description: | Table in which area stats are collected. |

# Appendix IV Changed methods and Objects

| Method | Changes |
|---|---|
| AreaTree.SingleArea.Request | If area is blocked, group gets new script by reassigning an Evacuation Script to the group. |
| AreaTree.SingleArea.CheckGroupWaiting | FlightInfoPointer changed. |
| AreaTree.SingleArea.EndActivity | Unique number check and VOID check introduced |
| Stats.SingleAreaStats.DepartFromArea | Set FirstPersonThrough and LastPersonThrough. |
| Stats.SingleAreaStats.Reset | Reset FirstPersonThrough, LastPersonThrough. |
| Stats.Stats.UpdateTally | Bug-fix statistics (by Edwin Valentin) |
| Control.ScheduleAndSignal.SignalSounds | Introduce possibility to stop calling for boarding if SignalAllowed = false |
| AreaTree.SingleArea.CheckGroupsWaiting | FlightInfoPointer changed. |
| Group.GroupControl.RequestArea | If not emergency then check if passenger is still on time. |
| Doorway.OnArrive | Set current exit as familiar exit |
| Doorway.HandlingTimeType.DetermineActionTime | Action time depends on door width and specific flow rate, not on resistance and walking speed. |
| SetDest.DetermineDestination | A possibility to use the parameter “EntranceUsed” to send groups to. |
| SetDest.CheckParameter | A possibility to use the parameter “EntranceUsed” to send groups to. |
| LeaveSystem.ScriptMethod | If emergency started, register the time that a group left the system in the evacuation control |

| Object or Frame | Changes |
|---|---|
| GroupGenerator.GenerateGroup | Counter to count the number of persons created is added to this frame. |
| AreaTree.SingleArea | AreaEmergencyControl added<br>AreaEvacControl added, method SingleArea.SetFamiliarExit added. |
| AreaTree.HandlingArea | Methods to store and reassign initial handling distributions have been added to AreaEmergencyControl. |
| Stats.Stats | EndWarmUpTime method added, to delete statistics at the moment an emergency breaks out. |
| Stats.SingleAreaStats | FirstPersonThrough, LastPersonThrough added |
| Script.ScriptStatement.LeaveSystem | EvacStats method added, to collect evacuation-specific statistics in case an evacuation scenario is executed. |
| Doorway.Dialog | Method HideLines added to take irrelevant lines from dialog box. |
| Icons | Added: emergency icon to all areas. |
| Control.ScheduleAndSignal.ScheduleAndSignal | Added: reset method to set back SignalAllowed:=true |
| Doorway.Stats | EndSimExitStats added, to register the statistics of the Emergency Exits |

# Appendix V New Evacuation Scripts

| Scriptstatement | Parameter 1 | Parameter 2 |
|---|---|---|
| SetDest | EntranceUsed | |
| LeaveSystem | | |

*Script "EvacScrFamiliarExit", which sends the group towards the exit it took when it entered.*

| Scriptstatement | Parameter 1 | Parameter 2 |
|---|---|---|
| SetDestClosestExit | | |
| LeaveSystem | | |

*Script "EvacScrClosestExit", which sends the group towards the exit that is closest to its current position.*

| Scriptstatement | Parameter 1 | Parameter 2 |
|---|---|---|
| SetDest | EXITNAME | |
| LeaveSystem | | |

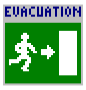
*Script "EvacScrChosenExit", which sends the group towards a user-defined exit. Instead of EXITNAME, the user should write the name of the exit to be used.*

Appendix VI

# Icons of Emergency and Evacuation objects

Emergency Control object

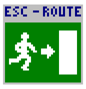
Area Emergency Control object



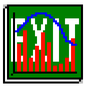
Evacuation Control object

Area Evacuation Control object

Emergency Exit object



Escape Route Compound Area object

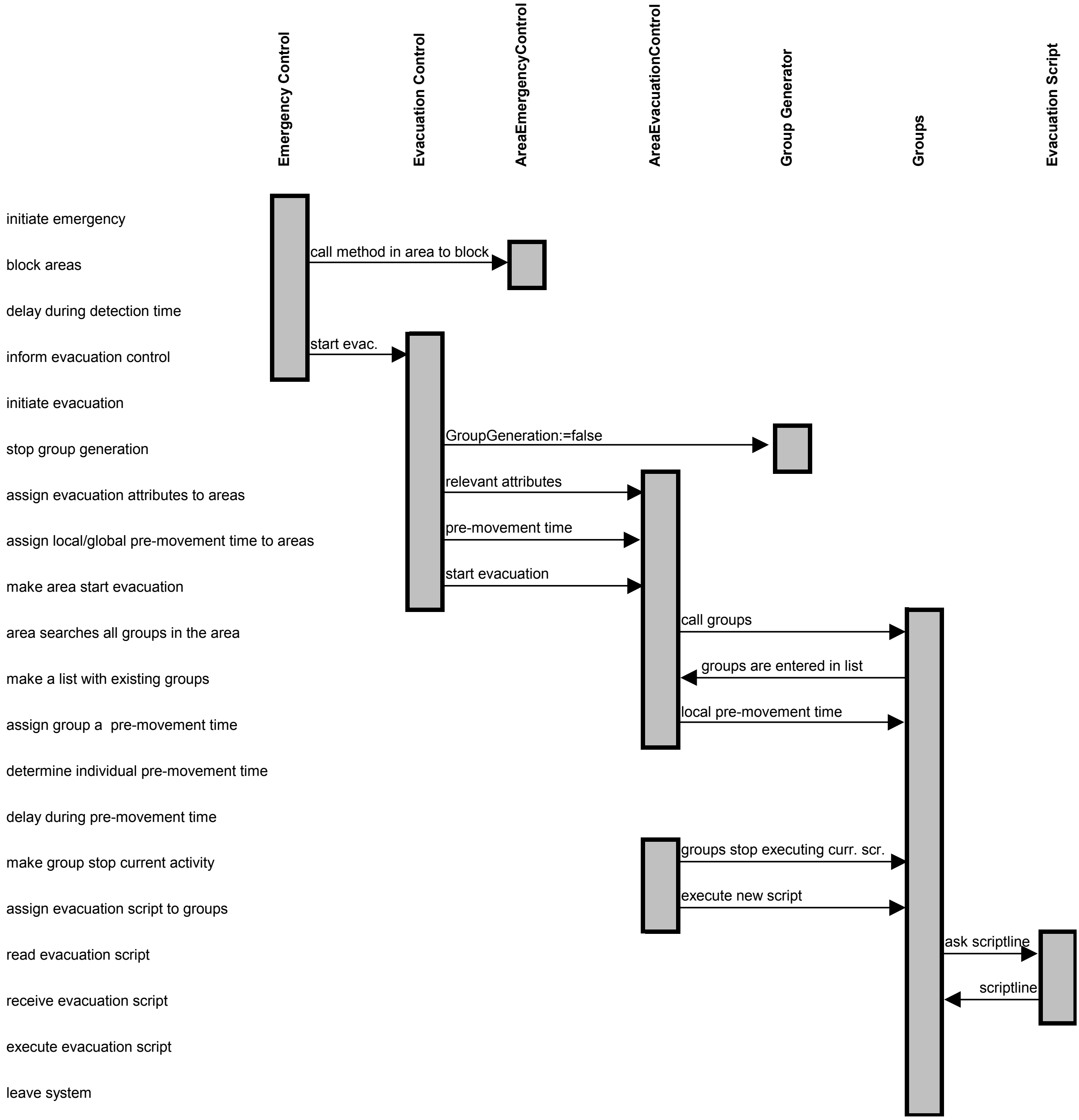

Evacuation Statistics object

Emergency Scripts

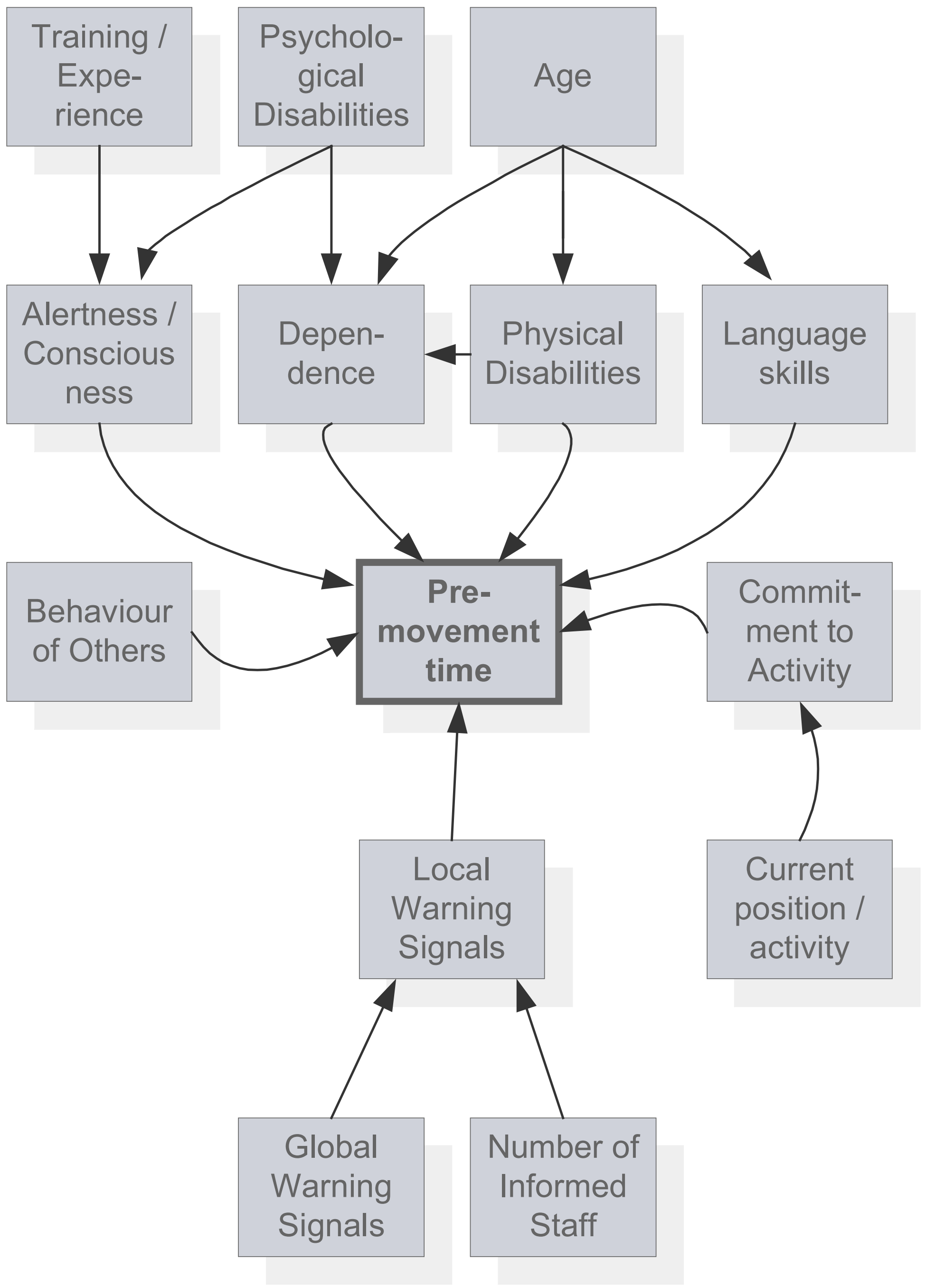
Script statement “SetDestClosestExit”

Internal Doorway object

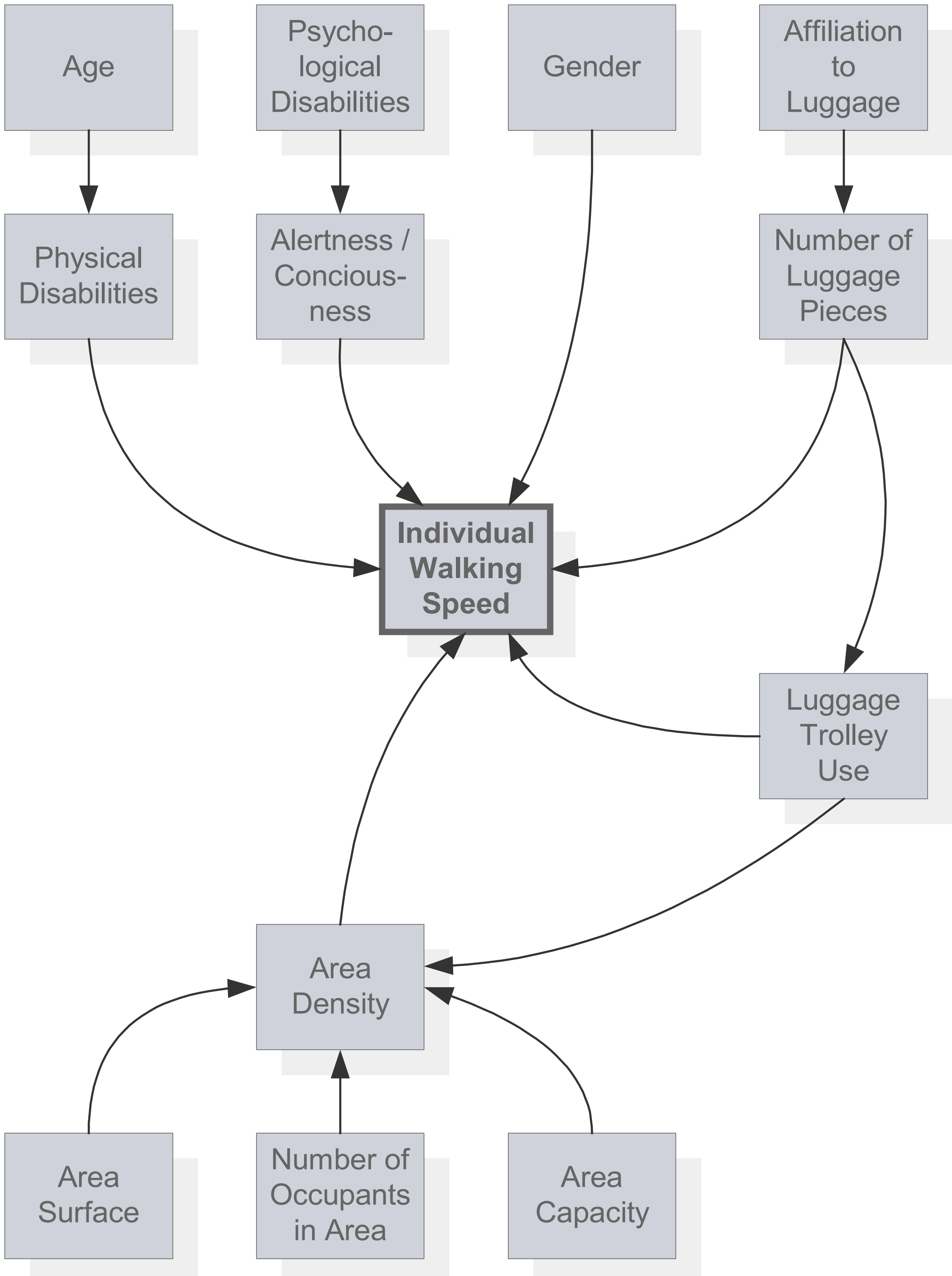
# Appendix VII Interaction model



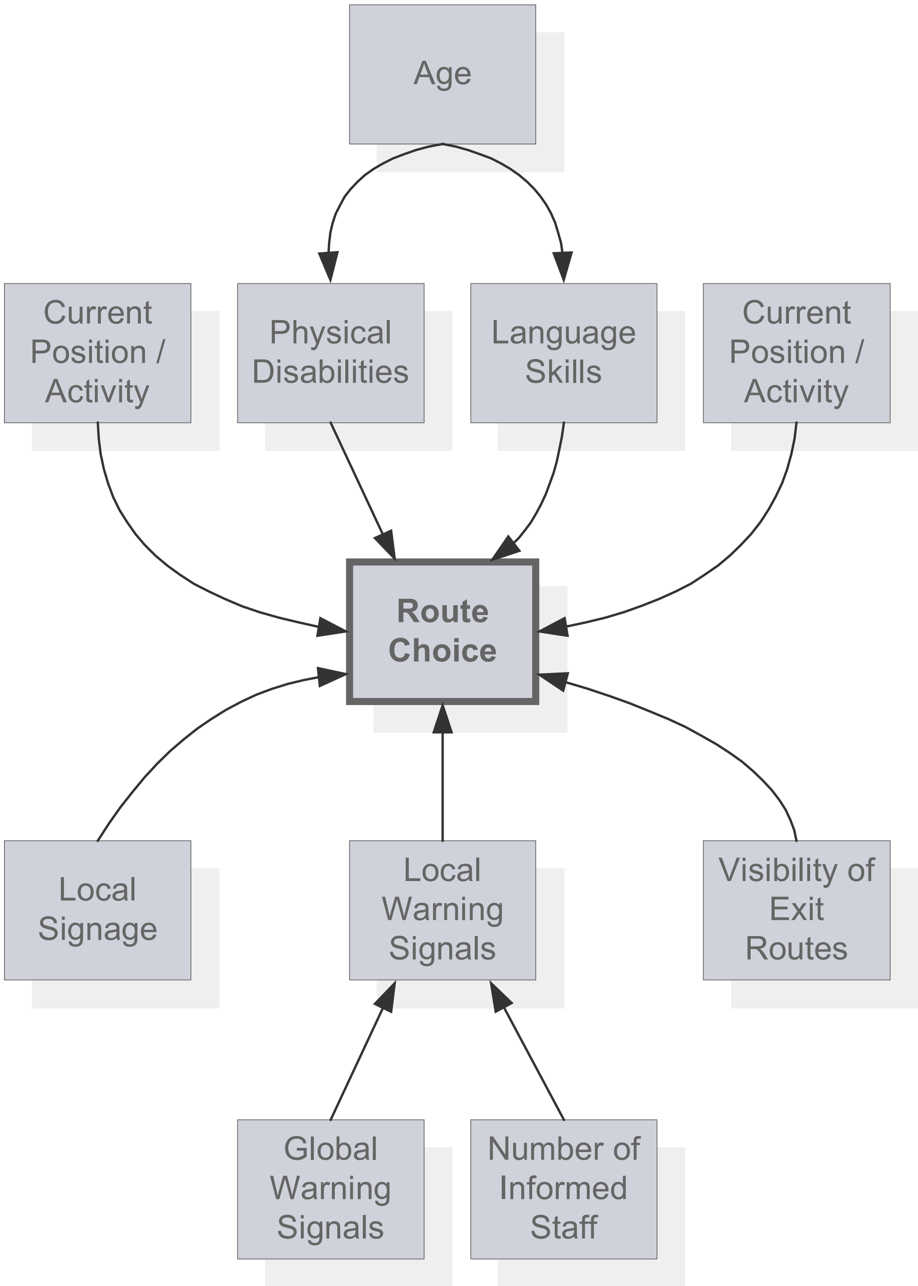
## Appendix VIII Influence Model – Pre-movement Time



## Appendix IX Influence Model – Individual Walking Speed



Appendix X **Influence Model – Route Choice**



## Appendix XI Model construction Safe Town Airport

### *Model construction*

#### Terminal layout modelling

| Area | Capacity | Resistance [m] | Handling Time |
|---|---|---|---|
| Curbside | 10000 groups | 0 | |
| Wait area | 225 m2 | 20 | |
| Check-in | 225 m2 | 20 | z_triangle(1,80,40,120) |
| Wait for passport check | 225 m2 | 20 | |
| Passport check | 2 groups | 10 | Step-based table |
| Walk area | 100 m2 | 10 | |
| Sitting area | 225 m2 | 20 | |
| Gate wait area | 175 m2 | 15 | |
| Boarding unit check | 50 m2 | 3 | z_triangle(1,15,5,20) |
| Bridge | 1000 persons | 15 | |

#### Flight schedule modelling

| Flight number | Number of passengers | Chancetable |
|---|---|---|
| KL1 | 150 | EU Passenger |
| KL2 | 45 | Non-EU Passenger |
| KL3 | 98 | EU Passenger |
| KL4 | 67 | EU Passenger |
| KL5 | 89 | Non-EU Passenger |
| KL6 | 134 | EU Passenger |

#### Population characteristics modelling

| EU Passenger | % | GroupSize distribution | Average groupsize | Arrival time | Script | Walk speed | Use of area | |
|---|---|---|---|---|---|---|---|---|
| Attribute name | | Nrperson-ingroup | | | Scripts | WalkSpeed | UseOfArea | TypeOf-Group |
| Type of attribute | | Real | | | Table | Real | Real | String |
| Function | | Once | 0 | | Once | Once | Sum | Once |
| Type of calculation | | Distribution | | Value | Value | Distribution | Distribution | Value |
| | 0.7 | 3 | 3 | EU_ARR_EC | Script | 1.0 | 0.8 | EU |
| | 0.3 | 1 | 1 | EU_ARR_B | Script | 1.5 | 0.5 | EU |

| Non-EU Passenger | % | GroupSize distribution | Average groupsize | Arrival time | Script | Walk speed | Use of area | |
|---|---|---|---|---|---|---|---|---|
| Attribute name | | Nrperson-ingroup | | | Scripts | WalkSpeed | UseOfArea | TypeOf-Group |
| Type of attribute | | Real | | | Table | Real | Real | String |
| Function | | Once | 0 | | Once | Once | Sum | Once |
| Type of calculation | | Value | | Value | Value | Distribution | Distribution | Distribution |
| | 0.6 | 2.5 | 2.5 | NEU_AR_EC | Script | 1 | 1 | NEU |
| | 0.4 | 2.5 | 2.5 | NEU_AR_B | Script | 1.5 | 0.5 | NEU |

### Population arrival time distributions modelling

| Start interval [s] | End interval [s] | Frequency |
|---|---|---|
| -10800 | -7200 | 0.3 |
| -7200 | -3600 | 0.3 |
| -3600 | -900 | 0.4 |

### Normal script modelling

| Scriptstatement | Parameter 1 | Parameter 2 |
|---|---|---|
| SetDestOrigin | Curbside | |
| SetDestGate | Constant | Boardwait |
| Waitforflight | | |
| SetDestGate | Constant | Board |
| LeaveSystem | | |

## *Evacuation modelling*

### Emergency exit modelling

| Exit | Width [m] | Width per person [m] | Specific flow [ps/m/s] |
|---|---|---|---|
| Entrance | 3.0 | 0.45 | 1.5 |
| EmergencyExit1 | 1.0 | 0.45 | 1.5 |
| EmergencyExit2 | 1.0 | 0.45 | 1.5 |
| EmergencyExit3 | 1.0 | 0.45 | 1.5 |

### Emergency growth modelling

| Name affected area | Starting moment since emergency start [s] | Emergency resistance |
|---|---|---|
| Gate2.Bridge | 30 | 100000 |
| SittingArea | 60 | 100000 |

| Parameter | Value |
|---|---|
| Emergency start | 27000 s |
| Detection time | 180 s |
| Growing emergency | False |

### Pre-movement time assignment modelling

| Parameter | Value |
|---|---|
| Pre-movement time assignment | Global |
| Pre-movement time distribution | z_triangle(1,60,30,90) |

### Evacuation script assignment modelling

| Parameter | Value |
|---|---|
| Evacuation script assignment | Global |
| Percentage using closest exit | 1.0 |
| Percentage using familiar exit | 0.0 |
| Percentage using chosen exit (i.e. EmergencyExit2) | 0.0 |
| Reassigned evacuation script | EvacScrClosestExit |

### Emergency procedure modelling

The exits are always accessible, and not centrally locked. Flight possibilities through the customs are possible.

### Evacuation procedure modelling

An integral evacuation will be performed.

| Parameter | Value |
|---|---|
| Emergency group surface reduction | 0.5 |

## Scenario design

| Scenario | Parameters | Expectations |
|---|---|---|
| Default scenario | | |
| Local script assignment | Locally assigned scripts, but same distribution as global assignment: Closest Exit (1.00), Familiar Exit (0.00) and Chosen Exit (0.00), for every area. | All occupants receive the same script they would have received globally, only locally assigned. Hence, there should not be a significant difference compared to the default scenario. |
| Local script assignment with different scripts | Public zone of the terminal goes to familiar exit, other parts to closest exit. | Structural validation which should show that all occupants get assigned a script. No expectations considering evacuation times. |
| Local pre-movement time assignment | Locally assigned pre-movement times, but same distribution as global assignment: z_triangle(1,60,30,90). | All occupants receive the same pre-movement time they would have received globally, only locally assigned. Hence, there should not be a significant difference compared to the default scenario. |
| Local pre-movement time with different distributions | Public zone (including Passport Check) of the terminal has a z_triangle(1,160,130,190) distribution, other zones the default distribution. | Structural validation which should show that all occupants get assigned a pre-movement time. No expectations considering evacuation times. |
| All to familiar exit | Script assignment table with the following input: Closest Exit (0.00), Familiar Exit (1.00) and Chosen Exit (0.00). | Long building evacuation time, long queues and queue times. All occupants leave through Entrance. |
| All to one particular exit | Script assignment table with the following input: Closest Exit (0.00), Familiar Exit (0.00) and Chosen Exit (1.00). The chosen exit is Emergency Exit 2 | Building evacuation time longer than default and than scenario with all occupants using familiar exit, longer queues and queue times. All occupants leave through exit 2. |
| All scripts | Script assignment table with the following input: Closest Exit (0.33), Familiar Exit (0.33) and Chosen Exit (0.34). | Structural validation which should show that all occupants get assigned a script. No expectations considering evacuation times. |
| Emergency with growth | Sitting area and Check-in will be closed after respectively 30 and 60 seconds. | Long building evacuation time because occupants get re-routed, longer queues and queue times. |
| Emergency with quick growth | Bridge and Sitting area will be closed after respectively 30 and 60 seconds. People are supposed to get trapped between these areas. | Structural validation to see if no occupants disappear. No expectation concerning evacuation time. Queue lengths may be shorter, because less people manage to escape. |
| Small population | Structural validation. All flights contain only one passenger. | Short building evacuation time and no queues. |

| Scenario | Parameters | Expectations |
|---|---|---|
| Large population | Structural validation. All six scheduled flights convey 900 passengers. | Long building evacuation time, long queues and queue times. |
| Population with low walking speeds | Walking speeds in chancetables between 0.5 and 1.0 m/s instead of normal 1.0-1.5 m/s. | Long building evacuation time, no significant effects on queues and queue times. |
| Population with high walking speeds | Walking speeds in chancetables between 2.0 and 2.5 m/s instead of normal 1.0-1.5 m/s. | Short building evacuation time, no significant effect on queues and queue times. |
| Doorways with large specific flow | Specific flow value set to 2.5 ps/m/s, for each exit. | Short building evacuation time, shorter queues and queue times. |
| Doorways with low specific flow | Specific flow value set to 1.0 ps/m/s, for each exit. | Long building evacuation time, long queues and queue times. |
| Doorways with large width | Widths of the doors get the following values: Entrance (6.0 m) and Emergency exits (4.0 m). | Short building evacuation time, shorter queues and queue times. |
| Doorways with small width | Widths of the doors get the following values: Entrance (1.0 m) and Emergency exits (0.5 m). | Long building evacuation time, long queues and queue times. |

**Remarks**

- Not the same group positions when emergency starts
- During creating of large amount of passengers appeared, that groups waiting outside the building are also evacuated towards the entrance. This has been changed. Persons outside building counter introduced.
- Change of walking speed does not have great impact on the building evacuation time. Change of specific flow of the doors or the door width, though, seems to have a more significant value. It should be noted, that this is not a generic conclusion, the terminal layout is decisive, concerning this matter.

# Appendix XII Results Safe Town Airport

| Scenario | Building evacuation time (incl. 180s detection time) | Time first group left | Time last group left | Number of groups created | Through Entrance | Through Exit 1 | Through Exit 2 | Through Exit 3 | Number of persons trapped | Number of groups initially outside | Maximum queue time (Exit) | Maximum queue length (Exit) | Conclusions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Default scenario | 6:13 | 7:33:38 | 7:36:13 | 350 | 8 | 12 | 117 | 213 | 0 | 0 | 59 (3) | 142 (3) | |
| 2. Local script assignment | 6:13 | 7:33:38 | 7:36:13 | 350 | 8 | 12 | 117 | 213 | 0 | 0 | 59 (3) | 142 (3) | Verified |
| 3. Local script assignment with different scripts | 6:02 | 7:33:38 | 7:36:02 | 350 | 38 | 0 | 114 | 198 | 0 | 0 | 51 (3) | 130 (3) | Verified |
| 4. Local pre-movement time assignment | 6:13 | 7:33:38 | 7:36:13 | 350 | 8 | 12 | 117 | 213 | 0 | 0 | 59 (3) | 142 (3) | Verified |
| 5. Local pre-movement time with different distributions | 6:23 | 7:33:44 | 7:36:23 | 350 | 8 | 12 | 114 | 216 | 0 | 0 | 51 (3) | 130 (3) | Verified |
| 6. All to familiar exit | 5:40 | 7:33:38 | 7:35:40 | 350 | 350 | 0 | 0 | 0 | 0 | 0 | 14 (E) | 100 (E) | Verified |
| 7. All to one particular exit | 7:39 | 7:33:44 | 7:37:39 | 350 | 0 | 0 | 350 | 0 | 0 | 0 | 109 (2) | 169 (2) | Verified |
| 8. All scripts | 5:42 | 7:33:38 | 7:35:42 | 350 | 115 | 5 | 168 | 62 | 0 | 0 | 59 (2) | 91 (2) | Verified |
| 9. Emergency with growth | 6:02 | 7:31:03 | 7:36:02 | 350 | 8 | 12 | 132 | 198 | 0 | 0 | 51 (3) | 130 (3) | Verified |
| 10. Emergency with quick growth | 5:53 | 7:31:03 | 7:35:53 | 350 | 8 | 12 | 132 | 0 | 198 | 0 | 30 (2) | 48 (2) | Verified |
| 11. Small population | 4:13 | 7:34:04 | 7:34:13 | 4 | 0 | 0 | 0 | 4 | 0 | 0 | 0 (-) | 0 (-) | Structurally valid |
| 12. Large population | 6:40 | 7:30:00 | 7:36:40 | 3249 | 450 | 248 | 266 | 198 | 0 | 2087 | 110 (1) | 242 (E) | Structurally valid |
| 13. Population with low walking speeds | 6:22 | 7:33:39 | 7:36:22 | 361 | 22 | 30 | 98 | 211 | 0 | 0 | 82 (3) | 139 (3) | Structurally valid |

| Scenario | Building evacuation time (incl. 180s detection time) | Time first group left | Time last group left | Number of groups created | Through Entrance | Through Exit 1 | Through Exit 2 | Through Exit 3 | Number of persons trapped | Number of groups initially outside | Maximum queue time (Exit) | Maximum queue length (Exit) | Conclusions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14. Population with high walking speeds | 6:09 | 7:33:36 | 7:36:09 | 359 | 11 | 21 | 110 | 217 | 0 | 0 | 58 (3) | 143 (3) | Structurally valid |
| 15. Doorways with large specific flow | 5:59 | 7:33:44 | 7:35:59 | 348 | 6 | 15 | 110 | 217 | 0 | 0 | 33 (3) | 89 (3) | Structurally valid |
| 16. Doorways with low specific flow | 7:19 | 7:33:44 | 7:37:19 | 338 | 5 | 17 | 107 | 209 | 0 | 0 | 104 (3) | 141 (3) | Structurally valid |
| 17. Doorways with large width | 4:42 | 7:33:37 | 7:34:42 | 350 | 8 | 14 | 114 | 214 | 0 | 0 | 2 (3) | 13 (3) | Structurally valid |
| 18. Doorways with small width | 8:37 | 7:33:46 | 7:38:37 | 350 | 8 | 12 | 114 | 216 | 0 | 0 | 129 (3) | 162 (3) | Structurally valid |

# Appendix XIII Model construction Schiphol F-Pier

## Model construction

### Terminal layout modelling

| Area | Capacity | Resistance [m] | Handling Time |
|---|---|---|---|
| Gate.BoardingUnitCheck | | | z_triangle(1,4,2,6)[104] |
| Gate.CleanCheckArea | | | 0 |
| Conveyors | | | 0.60 m/s[105] |

### Flight schedule modelling

| Flight number | Airline | Scheduled departure time | Actual departure time | Depart or Arrive | Number of passengers | Gate |
|---|---|---|---|---|---|---|
| KL0594 | KLM | 20000 | 20000 | Depart | 150 | PierF.F2 |
| KL0661 | KLM | 20000 | 20000 | Depart | 150 | PierF.F3 |
| KL0602 | KLM | 20000 | 20000 | Depart | 150 | PierF.F4 |
| DL039 | DELTA AIRL | 20000 | 20000 | Depart | 150 | PierF.F5 |
| KL0867 | KLM | 20000 | 20000 | Depart | 150 | PierF.F6 |
| TR884 | TRANSBRA | 20000 | 20000 | Depart | 150 | PierF.F7 |
| TR885 | TRANSBRA | 20000 | 20000 | Depart | 150 | PierF.F8 |
| VR622 | TACV | 20000 | 20000 | Depart | 150 | PierF.F9 |
| VR623 | TACV | 21000 | 21000 | Depart | 150 | PierF.F2 |
| KL0838 | KLM | 21000 | 21000 | Depart | 150 | PierF.F3 |
| KL0845 | KLM | 21000 | 21000 | Depart | 150 | PierF.F4 |
| 4X947 | FAIR | 21000 | 21000 | Depart | 150 | PierF.F5 |
| KL0603 | KLM | 21000 | 21000 | Depart | 150 | PierF.F6 |
| UK2074 | AIR UK | 21000 | 21000 | Depart | 150 | PierF.F7 |
| KL0474 | LM | 21000 | 21000 | Depart | 150 | PierF.F8 |
| KL0912 | KLM | 21000 | 21000 | Depart | 150 | PierF.F9 |
| UK2000 | AIR UK | 21000 | 21000 | Depart | 150 | PierF.F2 |
| KL0665 | KLM | 21000 | 21000 | Depart | 150 | PierF.F3 |
| KL0694 | KLM | 21000 | 21000 | Depart | 150 | PierF.F4 |

### Population characteristics modelling

| | Percentage | Groupsize distribution | Average groupsize | Arrival time | Script | Walk speed | Use of area | |
|---|---|---|---|---|---|---|---|---|
| Attribute name | | Nrperson-ingroup | | | Scripts | WalkSpeed | UseOfArea | Typeof-passenger |
| Type of attribute | | Real | | | Table | Real | Real | String |
| Function | | Once | 0 | | Once | Once | Sum | Once |
| Type of calculation | | Distribution | | Value | Value | Distribution | Value | Value |
| | 1 | Uniform (1,1,3.2) | 2.10 | ArrivalTimeTable | Script | Triangle (1,1.143, 0.635,1.1778) | 0.5 | "Economy" |

[104] from: Weghelaar, L. (1999); Balieplanningsregels NV Luchthaven Schiphol; measurements 1999

[105] from: Arends, D. (1999); Using Object-oriented Simulation for a Quantitative Approach of the Terminal Concepts; final thesis Delft University of Technology

## Population arrival time distributions modelling

| Percentage groups | Time Gatersleben | Time used |
|---|---|---|
| 0.01 | 3600 | 3800 |
| 0.02 | 3300 | 3500 |
| 0.04 | 3000 | 3200 |
| 0.05 | 2700 | 2900 |
| 0.06 | 2400 | 2600 |
| 0.06 | 2100 | 2300 |
| 0.11 | 1800 | 2000 |
| 0.12 | 1500 | 1700 |
| 0.12 | 1200 | 1400 |
| 0.14 | 900 | 1100 |
| 0.13 | 600 | 800 |
| 0.14 | 300 | 500 |

Gatersleben[106] distribution, increased with 200 s, the time it takes to walk 100 metres from the foot of the Pier to the gate with an average speed of 1 m/s.

## Normal script modelling

| Scriptstatement | Parameter 1 | Parameter 2 |
|---|---|---|
| Setdestorigin | PierF.GroupGeneration | |
| Setdestgate | Constant | Boardwait |
| Waitforflight | | |
| Setdestgate | Constant | Board |
| Leavesystem | | |

## Emergency modelling

| Name affected area (in chronological order) | Relative starting moment since emergency start (s) | Emergency resistance |
|---|---|---|
| PierF.W1 | 0.0000 | 100000 |
| PierF.f2.BoardingUnitCheck | 120 | 100000 |
| PierF.W1a | 180 | 100000 |
| PierF.F2.GateWaitArea | 180 | 100000 |
| PierF.F3.CleanWaitArea | 180 | 100000 |
| PierF.W2 | 360 | 100000 |
| PierF.F2.CleanAreaCheck | 360 | 100000 |
| PierF.F3.CleanAreaCheck | 360 | 100000 |
| PierF.ConveyorF3 | 360 | 100000 |
| PierF.ConveyorF4 | 360 | 100000 |
| PierF.F2.CleanWaitArea | 480 | 100000 |
| PierF.W3 | 480 | 100000 |
| PierF.F3.GateWaitArea | 480 | 100000 |
| PierF.W5a | 600 | 100000 |
| PierF.F3.BoardingUnitCheck | 600 | 100000 |

[106] Gatersleben, M.R. (1995); LOT P3; Amsterdam Airport Schiphol

## Emergency exit modelling

| Exit | Width [m] | Width per person [m] | Specific flow [ps/m/s] |
|---|---|---|---|
| Doorway | | 0.45 | 1.5 |
| EscapeRouteCentre.EmergencyExit | 2.0 | 0.45 | 1.5 |
| EscapeRouteLeft.EmergencyExit | 0.9 | 0.45 | 1.5 |
| EscapeRouteRight.EmergencyExit | 1.6 | 0.45 | 1.5 |
| F2.EscapeRoute.EmergencyExit | 2.0 | 0.45 | 1.5 |
| F2.EmergencyExit | 1.0 | 0.45 | 1.5 |
| F3.EscapeRoute.EmergencyExit | 2.0 | 0.45 | 1.5 |
| F3.EmergencyExit | 1.0 | 0.45 | 1.5 |
| F4.EmergencyExit | 1.0 | 0.45 | 1.5 |
| F5.EmergencyExit | 1.0 | 0.45 | 1.5 |
| F6.EmergencyExit | 1.0 | 0.45 | 1.5 |
| F7.EmergencyExit | 1.0 | 0.45 | 1.5 |
| F8.EmergencyExit | 1.0 | 0.45 | 1.5 |
| F9.EmergencyExit | 1.0 | 0.45 | 1.5 |

## Emergency growth modelling

| Name affected area | Relative starting moment since emergency start [s] | Emergency resistance |
|---|---|---|
| PierF.W1 | 0 | 100000 |
| PierF.F2.BoardingUnitCheck | 120 | 100000 |
| PierF.W1a | 180 | 100000 |
| PierF.F2.GateWaitArea | 180 | 100000 |
| PierF.F3.CleanWaitArea | 180 | 100000 |
| PierF.W2 | 360 | 100000 |
| PierF.F2.CleanAreaCheck | 360 | 100000 |
| PierF.F3.CleanAreaCheck | 360 | 100000 |
| PierF.ConveyorF3 | 360 | 100000 |
| PierF.ConveyorF4 | 360 | 100000 |
| PierF.F2.CleanWaitArea | 480 | 100000 |
| PierF.W3 | 480 | 100000 |
| PierF.F3.GateWaitArea | 480 | 100000 |
| PierF.W5a | 600 | 100000 |
| PierF.F3.BoardingUnitCheck | 600 | 100000 |

| Parameter | Value |
|---|---|
| Emergency start | 19800 s |
| Detection time | 180 s |
| Growing emergency | True |

## Pre-movement time assignment modelling

| Parameter | Value |
|---|---|
| Pre-movement time assignment | Local |
| Global pre-movement time distribution | irrelevant |

| Area | Local pre-movement time distribution |
|---|---|
| Areas empty when emergency break out, such as Emergency Exits and Escape Routes | 0 |
| Pier F2, W0 and W1 | z_triangle(1,30,15,45) |
| Piers F3 and F4, Areas W2 until W5a | z_triangle(1,60,40,70) |
| Piers F5 until F9, Areas W6 until W13 | z_triangle (1,120,100,140) |

## Evacuation script assignment modelling

| Parameter | Value |
|---|---|
| Evacuation script assignment | Global |
| Percentage using closest exit | 0.60 |
| Percentage using familiar exit | 0.40 |
| Percentage using chosen exit | 0.00 |
| Reassigned evacuation script | EvacScrClosestExit |
| Maximum number of re-routings | 3 |

## Emergency procedure modelling

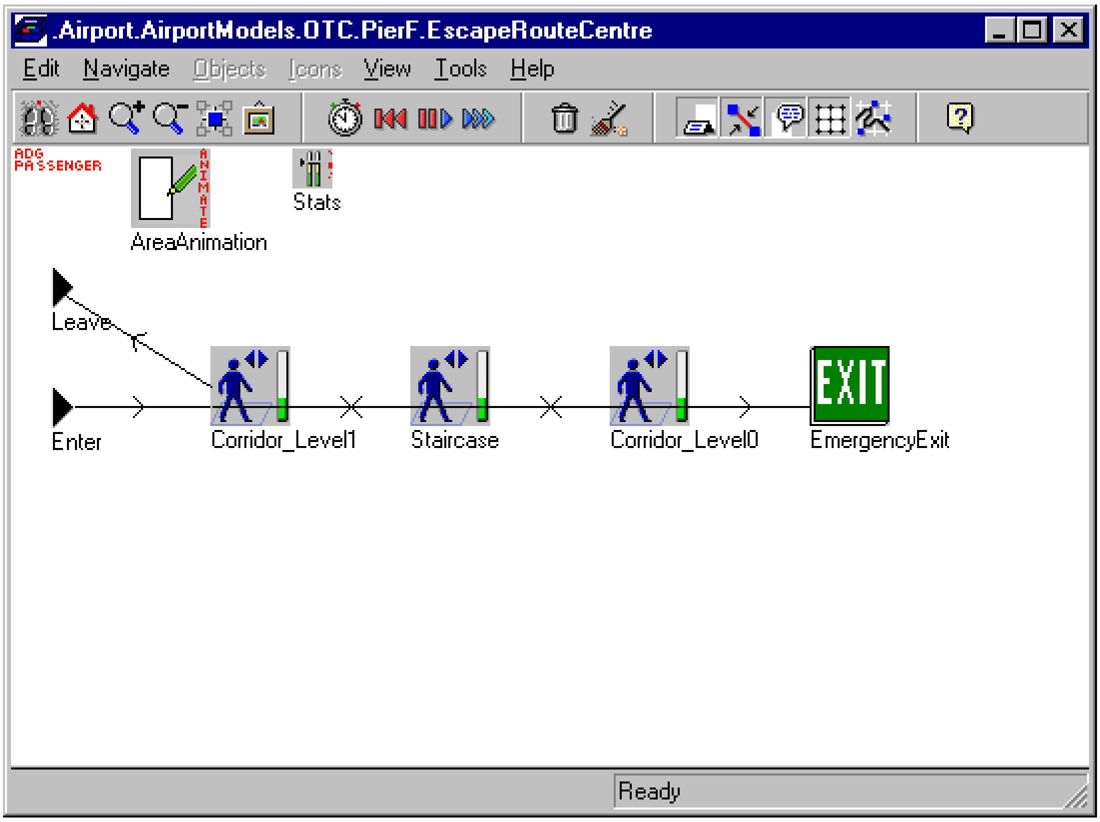
The exits at Schiphol are always accessible, and not centrally locked. Flight possibilities through the customs, and security controls are not relevant, since they are not located in the F-pier.

## Evacuation procedure modelling

An integral evacuation will be performed.

| Parameter | Value |
|---|---|
| Emergency group surface reduction | 0.5 |

## Appendix XIV Escape Route Compound Area



## Appendix XV Predictions Schiphol F-Pier

### Best case scenario with use of bridges (scenario 1)

**Peter van de Leur (TNO Centre for Fire Safety Research, Rijswijk, the Netherlands):**
,,Theoretically it could be about 3 minutes, considering the capacity of the available escape routes. But in reality it would probably not be quicker that six or seven minutes.‘‘

**Niels Bakker (Amsterdam Airport Schiphol, Safety Manager, the Netherlands)**
,,During an evacuation exercise, we evacuated 400 people in 5 minutes from one of our piers. I would guess that 2000 people could be evacuated from the F-pier in a maximum time of 10 minutes.‘‘

**Ruud Walters (Amsterdam Airport Schiphol, Project Manager Fire Safety, the Netherlands)**
,,I would say that the F-pier should be evacuated within 7 minutes.‘‘

### Best case scenario without use of bridges (scenario 2)

**Tom Heuer (Airport Research Center, Aachen, Germany):**
,,Considering the weakest and therefore critical point in the terminal during evacuations, namely the central staircase in the pier, I would say that the total evacuation time of the F-pier will be between 5 and 6.5 minutes.‘‘

# Appendix XVI Results Schiphol F-Pier

| | Scenario 1<br><br>Best Case –<br>All Exits | Scenario 2<br><br>Best Case -<br>Internal Exits | Scenario 3<br><br>Emergency –<br>All Exits | Scenario 4<br><br>Emergency -<br>Internal Exits | Scenario 5<br><br>No Emergency -<br>All Exits | Scenario 6<br><br>No Emergency -<br>Internal Exits |
|---|---|---|---|---|---|---|
| Start emergency (s) | 19800 | 19800 | 19800 | 19800 | 19800 | 19800 |
| Detection time (s) | 0 | 0 | 180 | 180 | 180 | 180 |
| Growing emergency | FALSE | FALSE | TRUE | TRUE | FALSE | FALSE |
| | | | | | | |
| Script assignment | Global | Global | Global | Global | Global | Global |
| Pre-movement time assignment | Global | Global | Local | Local | Local | Local |
| Global pre-movement time | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | |
| Number of persons created | 2022 | 2032 | 2022 | 2007 | 2028 | 2026 |
| Number of persons escaped succesfully | 2017 | 2029 | 1495 | 1478 | 2025 | 2023 |
| Number of persons trapped | 0 | 0 | 526 | 528 | 0 | 0 |
| Number of persons initially outside building | 2 | 3 | 2 | 1 | 3 | 3 |
| Number of persons left before emergency outbreak | 0 | 0 | 0 | 0 | 0 | 0 |
| | | | | | | |
| Time first group left (s) | 19801 | 19801 | 19803 | 19804 | 20004 | 20002 |
| Time last group left (s) | 20202 | 20679 | 20754 | 20950 | 21779 | 21881 |
| Total building evacuation time (s) | 402 | 879 | 954 | 1150 | 1979 | 2081 |

**Remarks**

- These results are average results of 5 replications.

# Appendix XVII Recommendations Airport Passenger Library

During this research we faced some problems concerning the Airport Passenger Library. In this appendix we will offer some suggestions to change objects or concepts of the existing library.

### Create a basic model

Building an airport model from scratch with the Airport Passenger Library is not an easy task. It is recommended to make the initial steps easier, by offering a basic model in which the user only has to define the most basic parameters, such as the terminal layout and the flight schedule. By means of one central dialog box, the user should have access to these basic input parameters. If the model is to be more sophisticated, the user could work on another level.

### Improve the animation possibilities

The animation part of the current library is at the moment one of the weaknesses. Creating an animation with the library is a complicated task. This is caused by the fact that the simulation model is not a one-to-one translation of the terminal layout. The spatial structure is represented by area objects, not by a grid with walls, through which occupants can move. Not only for evacuation analysis a better animation could be useful, but also for normal operations. Animation is a very important, if not essential, factor in model validation, since it can show how groups behave and how they move through the model. This way, it would be easier to identify bottlenecks and unrealistic behaviour.

### Do not delete passengers

It is not realistic to delete passengers that miss flight directly from the model, without letting them leave through a regular exit. The new objects and adaptation done during this research made it possible to re-route passenger that missed their flights to the exit where they entered.

### Consider real-time applications

The application of the Airport Passenger Library will have to meet airport demands. During interviews with Schiphol managers appeared, that they were interested in real-time applications, offering the possibility to determine possible bottlenecks within the terminal on day-to-day base. For example, the operational managers of an airport could insert the expected flight schedules and gate allocation table, in order to identify possible bottlenecks in the terminal building.

### Help function

Working with the Airport Passenger Library is at the moment only possible to those who are able to spend time on understanding the underlying structure. An additional help function and a complete reference guide would decrease the time necessary to learn to work with the objects.

# Appendix XVIII Modelling tips

In this appendix, we will give some short recommendations considering modelling evacuations using the Airport Passenger Library.

## Evacuation is bi-directional

One should realise that evacuation has a bi-directional aspect. People often escape into the direction where they came from. Therefore, there will always have to be a way back. The modeller should take care when using one-directional connections, since it might mistakenly create unnecessarily long escape routes.

## Create groups outside the terminal

Groups should enter outside the terminal building, so they will register a familiar exit, which makes it possible to execute the familiar exit script.

## Run shortest path algorithm after changes

After the change of the network representing an airport (e.g. the addition of emergency exits) the shortest path algorithm should be run in order to calculate the distances between every two areas.